

AN INNOVATIVE TIMBER CONSTRUCTION SYSTEM :
BUILDING AFFORDABLE HOUSING USING HOMEGROWN WELSH SOFTWOOD

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ABSTRACT

This thesis tests an approach to delivering affordable housing for rural Wales, through the design and development of a system of homegrown, re-engineered timber components for self build.

Recent studies and policy have demonstrated an acute shortage of affordable housing in rural Wales. Consequently, the Welsh Assembly Government has committed to deliver an additional 6,500 homes in the period 2007 - 11. However, there remains significant concern regarding the long term, sustainable delivery of affordable rural housing.

This dissertation proposes a solution to this need, based on the readily available resource of homegrown softwood. Sitka Spruce has become the primary production crop of the Welsh woodlands. It is rarely used in the construction industry due to its propensity to distort and instead is utilised in low value industries, including low grade carcassing timber. It is proposed that through an innovative and radical approach, homegrown timber resources can offer a high quality, locally sourced and sustainable modern method of construction.

In this study, a system of engineered homegrown timber components is designed, prototyped and tested as a self build construction solution for affordable housing in the diverse physical, social and economic context of rural Wales.

Design led studies, including a 'Pattern Book' of house types, and realised prototypical constructions are used to inform and interrogate the proposed components and construction methodology. The primary objective of these investigations is to examine the applicability and appropriateness for self build construction. Finally, through the construction of a whole house prototype, a system of homegrown timber components and an approach to its assembly is proposed.

Although limitations remain with this proposal, it has been possible to demonstrate that there is significant opportunity for an innovative, self build construction system using homegrown timber resources, to offer an efficient and sustainable solution for affordable housing in rural Wales.

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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 timber resources in the construction industry. Published in 2007 as a feasibility study, the investigation proposed that in order for a system of timber components to be adopted generally by the construction industry it would need to adopt an innovative and radical approach to timber frame construction methods.¹

Following the completion of my Masters in Architecture (RIBA Part II), during which time I focused on the role of making and prototyping in the realisation of architectural intent, I was invited to consider an opportunity to be part of the ongoing research related to homegrown timber in the construction industry.

Within the context of an ongoing research project, supported by a multi-disciplinary team of research partners, the broad scope of the subject area allowed great potential for a number of specific and unique research studies.

With academic interest in prototyping and making, and a personal interest in the role of self build within the construction industry, a research study developed around the topic of buildability and the potential for an innovative timber construction system, tailored to the specific properties of Welsh timber, to explore the opportunity for encouraging and enabling low skilled and inexperienced individuals to meet their need for affordable housing by constructing their own homes. Based on a socially driven ideology that the investment of sweat equity not only offers an alternative mechanism for delivering affordable housing in a mass developer driven residential sector, but also delivers much needed construction and manufacturing skills to a declining industry.

The methodology and objectives proposed within this study have been afforded the luxury of being centred on a funded ongoing academic and commercial development project

Under the working title “Ty Unnos- A house in a night” the project has, perhaps most successfully, enabled a multiple development route. A number of alternative streams of research and commercial objectives run in parallel, at times in partial conflict, but in the most part they have remained complementary and supportive. Considered as an ‘open source’ project, with significant public funding, the project has taken an inclusive and collaborative attitude, with the shared aim, to encourage the greater application of homegrown Welsh timber in the construction industry.

¹ Design Research Unit Wales + Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Welsh School of Architecture, 2007), p. 3.

It is within this context that I have embarked upon this research study. Founded on real data and experience, often shared with a number of parties, the aims and objectives of this study have been interrogated and reflected upon through a series of design based studies to consider the unique and original application of homegrown timber in the design of a buildable and innovative whole house construction system appropriate to the specific context of self build affordable housing for rural Wales.

Introduction

Ty Unnos - a house in one night

1.01 INTRODUCTION

Wales has approximately 300 thousand hectares of woodland, covering 14% of its total land area. Approximately 155 thousand hectares of this woodland cover is identified as coniferous plantations. Since 2001, Wales has produced 1 million green tonnes of softwood per annum with approximately 70% being harvested from Forestry Commission woodlands. It is estimated that approximately 70% of this production is Sitka Spruce, a native of the Pacific coast of North America. It has become the predominant species in Welsh publicly owned plantations because of its liking for the mild, wet climate and its ability to establish in peaty upland soils.

In its native range, Sitka Spruce grows slowly to a great age, producing a pale coloured timber with exceptional strength to weight ratio, leading to its use in the fabrication of aircraft frames. However, in Welsh plantations, Sitka Spruce typically grows much faster and maintains heavier branches, resulting in timber with a lower density and larger knots. In Wales it is processed for a number of markets including fencing, woodfuel, 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. This is readily available from timber merchants and sawmills in a range of standard lengths up to 4.8m, standard thicknesses of 47mm and 75mm and widths from 75mm to 250mm.

Although current production levels are stable and have established supply chains and markets, the growth, harvest and production of homegrown softwoods is considered to have limited commercial efficiency and sustainability. In general, production is used to supply low value markets, often as a ‘waste’ material such as pulp and wood fibre for paper and chipboard manufacture, or directly as firewood. This provides limited capacity to support the growth of supply chains and investment in sustainable woodland management. This has resulted in a woodland management system that is heavily reliant on public subsidy.

Due to significant changes to woodland strategy and political interests in woodland, in combination with an increased emphasis on sustainable construction techniques, interest in homegrown softwood resources and their role in the construction industry has become increasingly relevant and the subject of a number of research studies in the United Kingdom. Key to this interest is the vast economic potential that greater application by the construction industry can offer all sections of the timber industry and supply chain. Whilst there is interest and potential for this study to consider the entirety of the UK, the study will focus on the specific structure of the Welsh forest industry and unique properties of the Welsh resource, whilst considering the specific social and economic contexts of rural Wales.

Due largely to the increasing demands of sustainable and environmental performance, the proportion of timber frame used in house construction has dramatically risen in Wales in recent years to a market share of 25% in 2009, accounting for approximately 1250 of the 5000 new Welsh housing starts. A broad spectrum of timber construction systems are available worldwide however prefabricated open, closed and advanced timber frame panel systems, remain prevalent in the United Kingdom. Modern timber frame construction systems in the UK seldom use homegrown timber, with higher grades of imported C24 or TR26 softwood usually preferred. 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.

Following the publication of the Latham Report ‘Constructing the Team’ and the Egan Report, ‘Rethinking Construction,’ in 1994 and 1998 respectively, there has been an increased emphasis placed on the value of Modern Methods of Construction for the efficient delivery of better quality buildings. In particular this interest has focused on improving and increasing the delivery of housing to meet an acute shortage of affordable housing. Recent studies performed by the Wales Rural Observatory and the Joseph Rowntree Foundation have illustrated the severe extent of housing need currently witnessed in rural Wales. In response to these findings, in 2007 the Welsh Assembly Government published its One Wales agenda with a number of proposals and commitments to ease housing pressure. This includes improved guidance and policy interventions, increased availability of publicly owned land and greater flexibility to identify sites solely for affordable housing purposes. Perhaps most critically however was the commitment to increase the supply of affordable housing by 6,500 homes in the period 2007/8 to 2010/11. Whilst this objective was generally welcomed, a study conducted by the Joseph Rowntree Foundation concluded that with a net annual shortfall of 3,800 properties across Wales, and approximately 25,000 households on rural authority waiting lists, this target would not be sufficient to tackle the scale of the housing demand in rural Wales.²

The delivery of housing in the United Kingdom is heavily dependent on a small number of volume house builders. Consequently, the delivery of affordable housing is considerably exposed to commercial interests and the economic environment. Self build is a popular and successful method for delivering affordable housing across Europe and the USA. Local and national policies often encourage a greater availability of economically viable development land for the sole purpose of self build development. However, it is not actively encouraged within existing UK housing strategies, and there are limited examples of successfully realised community based self build projects. In addition to providing an alternative

2 Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008), p. 15.

mechanism for meeting affordable housing needs, it is the opportunity for local people to develop a range of valuable management, entrepreneurial and construction skills which makes this approach so encouraging.

In the current economic, political and construction climate it is clear that there is considerable opportunity to meet the acute need for affordable housing in Rural Wales through an innovative and radical approach to homegrown timber resources. It is this context that establishes the focus of the following research study.

1.02 RESEARCH PROPOSAL

Following the completion of a feasibility study into homegrown Welsh Timber in the construction industry, the Design Research Unit Wales, in partnership with Coed Cymru submitted the following research proposal to the Engineering and Physical Sciences Research Council;

At present all of the modern timber frame manufacturers in Wales (and the UK) use imported softwoods because of the greater stability and superior strength properties of slow grown softwood from cooler and drier climates. It was recognised that simple substitution with homegrown softwood was not an option. If a system was to be adopted generally it would need to stabilise the main structural components and eliminate the need for conventional trussed rafters. This would require a radical departure from existing practice.

Delivering a new construction system using homegrown timber is under development at many R&D centres, and a partnership consisting of the Welsh School of Architecture, University of Wales Bangor and Coed Cymru undertook a brief study funded by the Countryside Council for Wales and the Wales Forest Business Partnership. The study established an innovative construction system at the concept level through the use of:

modular glu-laminated post and beam structure, maximising the use of readily available, standard lengths and sections of Sitka spruce;

modular panel system based on spruce or other softwoods that can provide flexibility in use and adaptation in the future through wall, window and door positions;

- without the need to defect cut any spruce for laminating;
- using basic mechanical fixings such as brackets, plates and screws, to maximise the potential to disassemble the structure later.
- Sustainable (social, economic and environmental)

In order to establish the overall potential of this innovative use of homegrown timbers for construction purposes, it will be necessary to fully evaluate the properties of the product. Key to commercial development will be a thorough determination of properties related to design. To this end a range of design styles will be considered and assessed in terms of performance, durability and stability. This proposal will help address many of the outstanding issues for this innovative manufacturing system, and will help in the following ways:

- Making affordable timber housing a viable option;
- Using homegrown timbers;
- Meet sustainability issues (social, economic and environmental);
- Increase utilisation of local resources and personnel.

1.03 AIM

The primary aim of this study is to address the critical need for affordable housing in rural Wales using readily available homegrown timber resources through the application of low intensity and low technology manufacturing processes and simple and buildable construction methods appropriate to the existing industries and skills present in rural Wales including self build construction.

1.03.1 OBJECTIVES

In the pursuit of this aim, the following objectives will be considered as benchmarks against which the resultant construction system will be assessed;

LOCALLY SOURCED

The proposed construction solutions will make use of low value homegrown timber resources that are sustainably managed and harvested, and available to the industries of Wales in high quantity, specifically Welsh softwoods such as Sitka Spruce. The system will be specifically tailored to the unique physical and mechanical properties of homegrown materials to ensure as high a proportion of locally sourced material as possible can be utilised throughout the construction.

READILY AVAILABLE

Solutions will be tailored specifically to the existing timber supply chain making use of standard section and length material as commonly processed by the primary processing industries in Wales to ensure minimal waste and timber rejection.

SUSTAINABLE

Solutions will be designed to a performance specification that future proofs construction elements for continued appropriateness and adaptability to the changing standards of the UK construction industry.

Locally sourced sustainable materials and processes will be integrated throughout the construction including structural and thermal elements, windows, doors, and internal and external finishes.

In addition to these general working objectives there are two key objectives which establish the original contribution to knowledge within the parallel studies of the Ty Unnos project. These are;

MANUFACTURED IN WALES

The Welsh Forest Industry is a key element of the Welsh economy, providing

16,300 full time jobs³ and an annual revenue of £1.7 billion.⁴ However the industry is exceptionally fragmented with the majority of companies employing less than 10 people(71%)⁵ and achieving an annual turnover of <£20,000 to £500,000 (72%).⁶ The international marketplace demonstrates a large number of engineered high value, high quality and high capacity timber construction products, often manufactured in high quantity using highly mechanised manufacturing processes. Whilst simple substitution using Welsh-grown timber resources may be conceivable with a number of these products, it is highly unlikely that manufacturing facilities and processes could be transferred into the existing structure of the timber industry in Wales. Many international products have been facilitated by a scale of capital investment that the existing timber industry in Wales could not support or sustain.

There is however significant scope within the industry for collaboration and business diversification, building upon existing products, markets, resources and skills to deliver high quality and quantity products for the construction industry using methods appropriate to the Welsh timber industry.

The study will therefore focus on low intensity manufacturing processes considered appropriate to the existing timber processing industries of Wales, making use of existing skills, machinery and processes without the requirement for significant capital investment.

CONSTRUCTED IN RURAL WALES

The nature and scale of many rural development sites in Wales result in projects being embarked upon by small local developers and contractors. These development teams typically draw upon a relatively limited source of skills and resources and often rely on traditional construction methods. Construction innovation is therefore met with some trepidation, often due to the need to retrain and reinvest in order to deliver new processes efficiently and safely.

However, in addition, an objective for a simple, buildable construction solution goes beyond the wish to ensure appropriateness to the existing industry. Through a purposeful focus on buildability, it aims to enable individuals and groups with limited and no construction experience to develop appropriate construction skills, in order to encourage 'Self-build' as an opportunity for delivering affordable housing in rural Wales.

Therefore, the development of an innovative construction method based on

3 Jaakko Poyry Consulting, *Welsh Forest Industry - Mapping and Benchmarking the Forest Industry – Final Report* (London: Jaakko Poyry Consulting, 2004), p. 30.

4 Jaakko Poyry Consulting, *Welsh Forest Industry - Mapping and Benchmarking the Forest Industry – Executive Summary* (London: Jaakko Poyry Consulting, 2004), p. 4.

5 Jaakko Poyry Consulting, *Welsh Forest Industry - Mapping and Benchmarking the Forest Industry – Final Report*, p. 30.

6 Ibid., p. 22.

homegrown timber resources will be tailored to the construction industry present in rural Wales, making use of existing skills, machinery and processes. Construction processes will be designed with great attention for ease and simplicity so that methods can be easily disseminated and incorporated into the services of general contractors, and through basic training, taken up by alternative groups with limited construction experience.

Construction processes should also be appropriate to the context of Rural Wales, taking into consideration the challenging factors of site access, geology and topography, and often extreme variations in climatic conditions, in addition to a sensitivity to the diverse historical, social and landscape context experienced across rural Wales.

1.04 HYPOTHESIS

Homegrown softwoods can be re-engineered using low technology and low intensity manufacturing processes to provide a self build affordable rural housing solution.

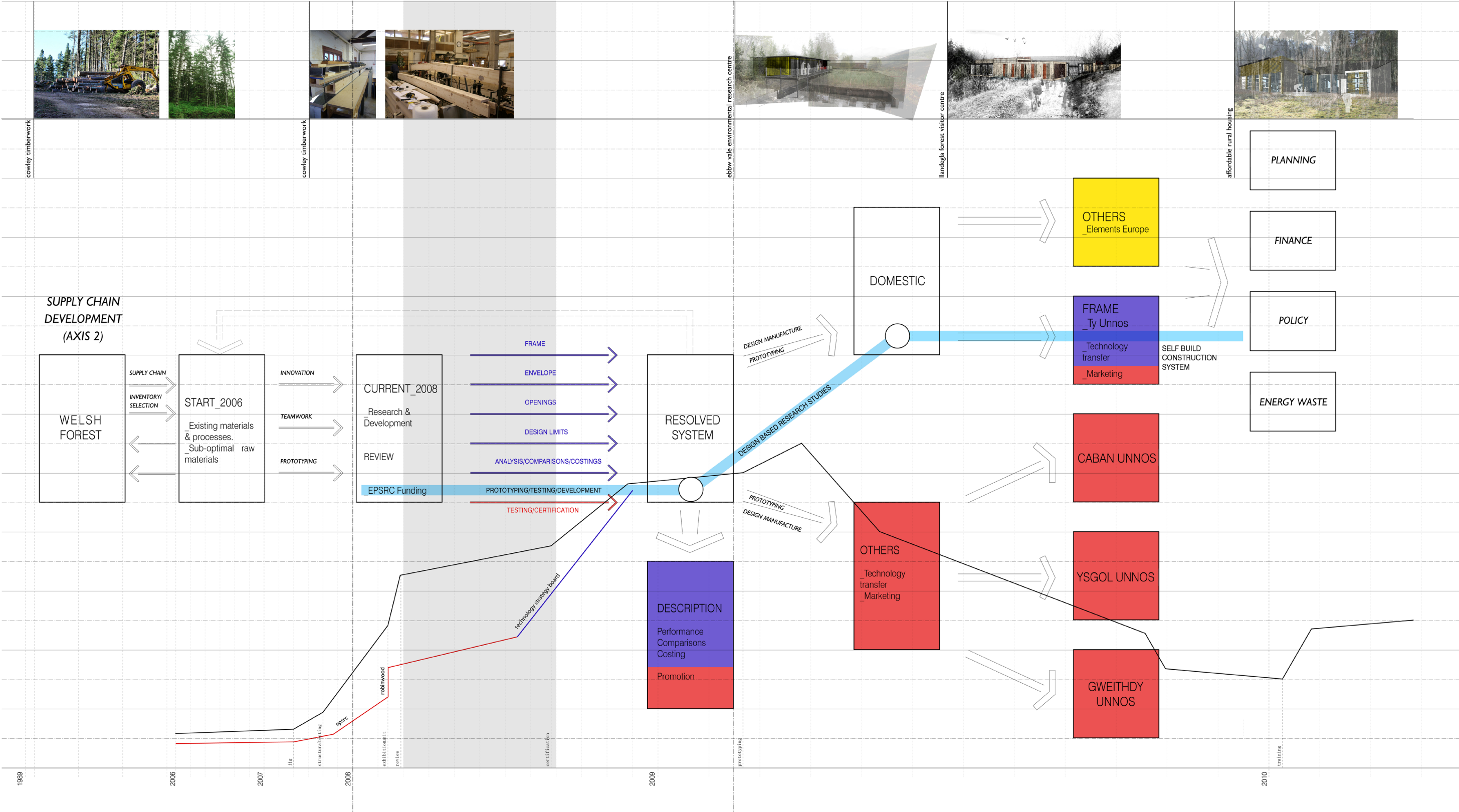


Figure 1.1: Proposed routemap of delivery for the increased application of homegrown timber in the construction industry.

1.05 RESEARCH STRUCTURE

1.05.1 TY UNNOS “A HOUSE IN ONE NIGHT”

In 2006, the woodland management charity Coed Cymru were asked to consider the greater application of Welsh softwood in the construction industry. Coed Cymru, with funding from the Countryside Council for Wales, subsequently commissioned a feasibility study to identify the opportunities and barriers to the use of homegrown timber in the construction industry. The project team, including timber specialists Cowley Timberwork, the Design Research Unit Wales and Bangor University concluded that, due to the greater stability and superior strength of existing supplies of slow grown imported softwood, it would not be possible to simply substitute home-grown timber into existing timber frame manufacture. If a system was to be adopted generally it would need to stabilise the main structural components and eliminate the need for conventional trussed rafters.⁷

The study proposed a radical departure from existing practice. Drawing on the 20th Century precedent of Jørn Utzon's Espansiva system, the study proposed a modular system of laminated portal frames based on a simply laminated hollow box section structure. The resulting structure is light but very strong and stable and can be infilled with naturally sourced insulations. A lightweight box panel with the same external dimensions was proposed as a high performance insulated infill panel for walls, roof and floor that could combine with coordinated doors and windows to form an entire building envelope. Building on the ideas of Jørn Utzon, the kit of parts were combined into 5 standardised modular pavilions, with a column in each corner and standardised roof pitches of 17.5, 25 and 35°. Based on standard, readily available timber lengths and sections, and a 600mm basic layout grid, the 5 pavilions are conceived as a series of modular rooms varying in sizes from 1.2m x 3m to 4.8m x 3m, or from entrance lobby to small bedroom to kitchen to living room. When combined, the room modules offer limitless opportunities for the creation of house types as an appropriate solution to providing affordable sustainable housing for Wales.

The proposed system was given the title Ty Unnos 'a house in one night' after the Welsh tradition, dated to the 17th Century, when it was believed by some, that a person may build a home on common land and take ownership of the land as freehold, if the house is complete, with smoke in the chimney, by the time the sun rises.

7 Design Research Unit Wales + Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Welsh School of Architecture, 2007), p. 3.

1.05.2 THE ‘ROUTEMAP’

Following its publication in October 2007, the study received widespread interest and the Project Team began the process of actively pursuing funding to undertake detailed prototyping, development and testing in order to construct a dwelling by 2009. Early in this process, a successful application was made to the EPSRC for the funding of a 3.5 year PhD research study, to the brief shown in Section 1.02.

In the academic year 2007 - 2008 the Ty Unnos study was extensively marketed in the public realm. This included major public events such as the Royal Welsh Show and the National Eisteddfod, and dissemination events hosted by the Welsh Assembly Government, the Prince’s Foundation for the Built Environment and local county councils and community groups. This took many forms, from formal presentations to informal meet and greets and exhibition stands.

Conceived as an open market product, the project team actively pursued relationships with a number of innovative and creative members of the Welsh construction industry and timber supply chain. A number of companies took great interest in the development of the project, each identifying and exploring opportunities for the use of Sitka Spruce in construction. As conceived the Ty Unnos system potentially lends itself to various levels of prefabrication, from whole house volumetric construction, to a component based frame and panel system as originally proposed.

In addition to interest from the industry, the project team were also approached by a range of clients with interest in using the proposed system for potential projects. Initially this was informal and typically vague, however a number of challenging projects crystallised into design commissions. Although considerable interest was shown by the public sector, formal funding was not forthcoming and the project team turned to the emerging project commissions and private sector interest to further the process of structural testing, development and certification, and to consider parameters such as economic and environmental performance.

Following my introduction to the Project Team, I was asked to consider and illustrate the potential applications of homegrown timber in the construction industry in the form of a ‘Routemap’. The routemap, shown in Figure 1.1, identified a range of applications from individual engineered timber components, to factory manufactured volumetric solutions and prefabricated whole building systems for the construction of homes, schools and other building types.

The study proposed that from a collaborative and open source of product development, testing and certification, a broad range of markets and opportunities could be explored and developed by project partners and other interested parties. This broad market interest would enable the project partners to then revisit the supply chain, encouraging investment, development and a



reassessment of current strategies, processes and products and enable the whole supply chain structure to capitalise on higher value and more sustainable markets than currently pursued.

The routemap illustrates a wide range of potential opportunities for the application of homegrown timber in the construction industry. With Coed Cymru as the lead organisation, a multi-disciplinary team including design consultants, suppliers, manufacturers, housing developers, academic institutions and social housing providers formed with the collective aim of exploring some of the potential strands of the market. Initially focused on the key sector of housing, two working groups were formed; the Technology Strategy Board funded ‘Sustainable housing from Sitka Spruce’ led by the Design Research Unit Wales and Coed Cymru and the Ty Unnos Modular commercial project led by Elements Europe.

SUSTAINABLE HOUSING FROM SITKA SPRUCE

In late 2008 the Project Team, led by Coed Cymru, applied and were awarded funding from the Technology Strategy Board under the Low Impact Buildings Innovation Platform.

The project put forward the aim;

“to take forward the results of previous basic research and overcome the technical barriers and economic challenges in the development of Sitka spruce in an integrated whole house system for low carbon affordable housing.”⁸

The application proposes an ambitious two year programme of development to take to market a complete, certified whole building system including whole house design and performance, component manufacture, panel construction and performance, component interfaces and buildability. The project was awarded funding and commenced in January 2009. Under the project proposal, two building studies have been completed by the Project Team in order to develop and apply findings of the study. Following its completion in 2011, the resolved system has been the subject of an application for an ETA under ETAG 007 Timber Frame Building Kits which, at time of writing, is awaiting completion.

OPPOSITE PAGE

- Figure 1.2: Ty Unnos Modular employed to construct 4 affordable housing units, Glan Gors, Dolwyddelan
- Figure 1.3: Floor assembled open roof frame of ladder beams and plates lifted into location in the factory.
- Figure 1.4: Open wall frame being installed,
- Figure 1.5: Volumetric unit transported to site fully finished.
- Figure 1.6: Lifting the volumetric unit onto prepared foundations.
- Figure 1.7: Ground assembled roof truss structure being lifted into place onto the installed modules.

TY UNNOS MODULAR

In 2008 volumetric manufacturer Elements Europe and other members of the Pickstock Group became aware of the Ty Unnos feasibility study and a close relationship was formed between Elements Europe and the Project Team. Elements Europe identified the unique product opportunity for a homegrown timber based volumetric construction system for housing. Working with members of the project team, Elements Europe identified a brief and specification focused on the bringing to market of a volumetric solution.

8 Design Research Unit Wales + Coed Cymru, *Technology Strategy Board : Components and Materials for Low Carbon Buildings : Full Stage Application Form* (Cardiff: Welsh School of Architecture, 2008), p. 2.

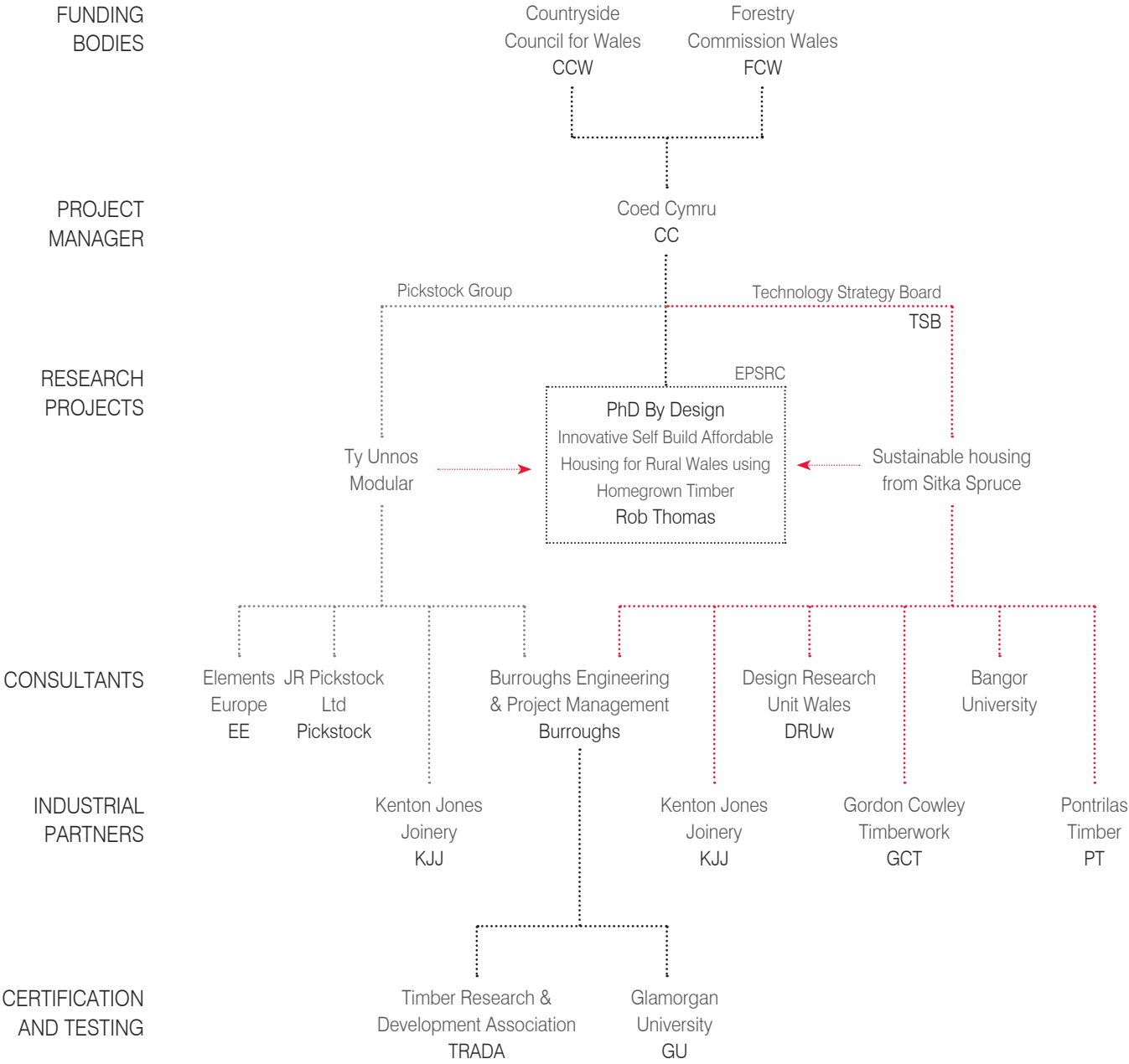


Figure 1.8: Members and Structure of the Project Team

The Modular project has provided consistent funding and drive for the testing and certification of component prototypes developed by the Project Team. The resultant manufactured system, illustrated in figures 1.2 - 1.7, has successfully fulfilled the assessment process outlined in ETAG 007 Timber Frame Building Kits, and has been employed for the delivery of approximately 14 housing units at time of writing. Commercially the intellectual property and certification of the Ty Unnos Modular project remains the sole possession of Elements Europe, however the development process has resulted in considerable knowledge transfer between all members of the Project Team.

1.06 RESEARCH METHOD

It is proposed that the aim and objectives of this research will be informed, interrogated and concluded through a series of design based investigations.

This research study will be considered in two parts, the first section, chapters 2 and 3, will establish the specific and unique context of the study through the consideration of current policy, published research and key texts. This will firstly identify and define the diverse and acute need for affordable housing in rural Wales and the existing approach to the provision of affordable housing. A study of the resource, the primary softwood crop of Sitka Spruce, will then establish the specific properties of the timber and the opportunities and limitations that will determine its application as a high quality, sustainable construction material. A study of current national and international construction practices will then establish the market, skills and opportunities for an innovative approach to timber construction and, through the analysis of case study systems, look to identify potential precedents for innovative design.

The second stage of the research study will employ a number of design based research mechanisms to prototype, test, develop and inform the application of homegrown timber components to the unique requirements of affordable housing for rural Wales, culminating in the manufacture and construction of a full scale prototype.

The Ty Unnos project, as demonstrated in Fig. 1.1. has a number of alternative streams of research and commercial objectives which run in parallel, sharing a comprehensive source of data and experience. My relationship with Coed Cymru and the Design Research Unit Wales has enabled me to adopt a central role in this collaborative project from which I have been encouraged to contribute to and draw from this source of ongoing data and experience. This has included taking an active role in: prototyping and manufacturing, component testing, consultation, including team meetings and research dissemination with

commercial and project partners, funding bodies and interested parties, such as the Prince of Wales Trust, the Welsh Assembly Government and Local Authorities, and informing the direction of learning objectives and future development.

In the following study, a methodology has been established which combines contributing to, recording and analysing the collaborative work of the project team with a series of individual investigations specifically defined to address the unique objectives of this study.

1.06.1 MY ROLE

The following is a brief introduction to the methodology and role that I have undertaken during the development of this research project. The PhD is a review of a series of design based studies undertaken over a period of three and a half years, completed by myself in conjunction with my industrial partner Coed Cymru and the Welsh School of Architecture's Design Research Unit Wales (DRUw).

The purpose of this introduction is to concisely describe my role in these investigations in order to clarify the origin of research investigations and findings.

In the following chapters I will attempt to identify the primary source of original research data, and provide a general overview of my role within each stage of the project. For clarity, the following summary is simplified as an essentially chronological description of the research methodology. However many of the following studies have run in parallel and with significant overlaps.

COMPONENT 01 : HOLLOW BOX SECTION BEAM

I joined the project following completion of the original feasibility study, as Coed Cymru was undertaking initial testing and the development of the manufacturing techniques of a structural box section in conjunction with Cowley Timberwork. My initial involvement in this development process was limited to the recording and reviewing of the process and results.

PROTOTYPICAL STUDY 01 : LLANDEGLA FOREST VISITOR CENTRE

Initial input to the development process, and the development of a focused research methodology, began with a design 'primer' at Llandegla Forest. The project, described in Chapter 8.0 has been approached as an opportunity to gain an understanding of the system as a structural and spatial approach. As an Architectural Assistant for DRUw, I therefore led the generation of concept designs and detailed design proposals to tender stage.

PAPER STUDY 01 : PERFORMANCE SPECIFICATION

The Llandegla prototypical study identified the critical need to define the specific performance requirements of the 'Affordable Housing' Sector for the purposes

of this study. This takes the form of a performance specification discussed in Chapter 5.0 as a review of current literature, building standards and cost data. The specification is unique to this research study and has been used by the Project Team to inform the testing and development of system components.

In the form of paper based studies, the Performance specification has then been applied to the design of dimensional and structural arrangements, and subsequently room arrangements to test for structural and material efficiency, buildability, space standards and flexibility.

These studies have subsequently informed the design and initial prototyping of a 600mm based thermal panel system by Coed Cymru and the project partners.

PROTOTYPICAL STUDY 02 : ENVIRONMENTAL RESOURCE CENTRE

The Environmental Resource Centre has provided the first opportunity to apply the proposed construction components in a ‘real’ construction scenario and further the detailed design findings of the Llandegla Forest prototypical study.

Working with a design team from DRUw, including project Architect Steve Coombs, my role in the project again reflected a traditional Architectural Assistant role, including contributions to initial concept designs, planning and tender information and the detailed design of a number of system interfaces.

This role afforded the opportunity to contribute to and record the design process including attendance at design team and client meetings, and a close monitoring of onsite construction and manufacturing.

COMPONENT 02 : LADDER BEAM 01

In parallel to the development of prototypical studies, the industrial partners began the prototyping and testing of a second homegrown timber engineered component in the form of a short span joist or wall stud replacement.

This followed a cyclical process of formal and informal testing and prototyping informed, in part, by the findings of my investigations into space standards and component efficiencies. My role in this process has included: recording and reviewing prototypes and formal testing, informing performance requirements, and working with Coed Cymru to propose and prototype alternative ladder beam geometries.

PROTOTYPICAL STUDY 3 : THE WELSH FOLKLIFE FESTIVAL PAVILION

The Smithsonian Pavilion has provided the opportunity to apply the tested Ladder Beam 01 component in the form of a standardised and interlocking system of infill panels. Informed by the findings of earlier prototypical and paper-based studies, the detailed design and construction of the Pavilion has followed an alternative approach, more closely reflecting the research objectives of this study.

Personal contributions to the Pavilion include input into the detailed design of panel interfaces and the production of manufacturing information. Once again I have been given the opportunity to monitor and review the construction process and record feedback from the manufacturing and construction team.

PAPER STUDY 02 : DESIGN PATTERN BOOK

Informed by findings from paper-based investigations into dimensional and structural arrangements, component testing, and the prototypical studies, it has been possible to develop a set of 'design rules'. These design rules are proposed as a method of determining the design of room arrangements and dwellings to make efficient use of a system of standard components.

This design methodology has subsequently been applied and tested in the form of a Pattern Book of House Types described in Chapter 7.0. Although employed as a useful source by the Project Partners, specifically to inform the performance requirement of structural components, the approach and outcomes of this paper-based study is considered entirely original to the thesis.

PROTOTYPICAL STUDY 04 : WELSH PASSIVE HOUSE

The final prototypical study has enabled the significant advancement of both paper based studies and home grown timber components through their application to a 'real' domestic construction scenario.

My role in this project has been significant, working closely with the project Architect Steve Coombs of DRUw and the consultant team, to inform design proposals based on the results of the thesis studies, including the Pattern Book of House Types and Performance Specification, and the detailed design of the structural and thermal envelope. This role has involved leading the production of detailed manufacturing drawings, including close consultation with the manufacturer Kenton Jones regarding tolerances, standardisation and manufacturing efficiencies, and assembly process.

The conclusion of the Welsh Passive House prototypical study resulted in a broad number of results and many unresolved questions related to detailed design ideas, connections, manufacturing efficiencies and most specifically, the appropriateness of the componentary to the skills and abilities of the rural communities.

This has provided the basis for the primary investigation of this thesis.

COMPONENT 03 : LADDER BEAM 02

The primary study began with a review of the ladder beam element. Based on existing manufacturing processes prevalent in the packaging industries, the industrial partner Coed Cymru and myself began experimenting and informal

testing with laminations of small section home grown spruce to form nailed, screwed or glued laminated ladder beams.

PRIMARY STUDY : RURAL STUDIO TREGYNON

The Primary Study is considered as a full scale experimental prototype, designed as an apparatus to perform a number of focused experiments into detailed design, manufacture and buildability. The structure is split into a number of bays, and bays into elements, with each element testing an approach in order to inform the aim and hypothesis of this thesis.

The study has been performed with significant assistance from Coed Cymru, including use of private workshop facilities, manpower and financial backing and also from Burroughs engineering. However, the study has been performed by myself, in most part independently, in order to inform and conclude the original research objectives identified in this thesis. This study has included: the application of individual creative thought to the design of components and buildings, prototyping, testing, manufacturing and constructing, from the scale of component to full scale construction, recording and analysing results.

1.07 THE TY UNNOS ‘PROJECT TEAM’

The following organisations have been consistent contributors to the broad development project entitled ‘Ty Unnos - A house in one night’, in which this study forms one strand of specific research.

COED CYMRU - CC

In 1985 a partnership of organisations established Coed Cymru as a campaigning body to heighten awareness of native woodlands in Wales, which following a century of neglect and plunder, were in a state of serious decline. The charity organisation began as a network of woodland advisors providing free and impartial help, advice and training to all members of the timber supply chain. It now acts as a catalyst for the development of sustainable woodland management particularly focused on the Welsh broadleaf woodlands, promoting co-operation between woodland owners, contractors and timber users.

Coed Cymru's role has evolved to include prototyping and developing products that make use of and add value to the Welsh timber resource. Initially this focused on the use of small hardwood trees producing small sections of timber, perceived to have little economic value. Coed Cymru have developed methods of milling and manufacturing that make valuable use of these small hardwood supplies for uses such as high quality furniture, flooring, windows, toys and giftware.

DESIGN RESEARCH UNIT WALES - DRUw

The Design Research Unit Wales is an architectural design practice within the Welsh School of Architecture. It was established in 1997 with the aim of founding the creative activities of a high level design studio on a sound research-based approach. The work of the studio has received national recognition, including being shortlisted for the Young Architects of the Year Award 2007 and 2010 and publishing projects in the Times and Building Design papers and featured on the BBC Culture Show.

DRU-w and the Welsh School of Architecture have pioneered research in housing since the energy crisis of the 1970s, developing sustainable, low energy housing in partnership with affordable social housing organisations. The Ty Unnos project has enabled DRU-w to build on this research with the development of a whole house construction system using locally sourced materials.

ELEMENTS EUROPE - EE

Elements Europe Ltd specialise in the development of off-site construction solutions. The company have an established product line of light steel frame structures, manufacturing fully fitted units including bathroom and kitchen ‘pods’ and whole room volumetric units manufactured at a highly mechanised facility in Oswestry. Ty Unnos, as an all timber product, is a new venture for the

company. The company have embraced the principles of using locally sourced materials and components and are developing residential units which achieve high environmental performance at low cost.

KENTON JONES JOINERY - KJJ

Kenton Jones Joinery Ltd design and craft kitchens and bathrooms and manufacture solid wood flooring from their factory in Welshpool, and are a leading advocate for the use of homegrown timber. Their equipment and skills and an innovative attitude have enabled them to adapt easily to the manufacture of Ty Unnos components. From its inception Kenton Jones has recognised the exciting potential of the Ty Unnos system and been critically involved in the development and manufacture of Ty Unnos components. At the time of writing KJJ are the only active manufacturer and supplier of Ty Unnos components.

COWLEY TIMBERWORK - CT

Cowley Timberwork are one of the UK's leading timber engineering and manufacturing companies. They have been involved in a succession of high profile, award winning projects such as the Scottish Parliament, Peckham Library and Maggies Centre, Dundee. They have developed a wide experience and knowledge of timber engineering from complex geodesic dome structures to simple garden rooms. Cowley Timberwork were appointed in 2007 as consultants for the initial Ty Unnos feasibility study to consider the use of Welsh Sitka Spruce in the construction industry, and thanks largely to their experience and creativity, the initial concept for a structural hollow box section was derived.

BURROUGHS

Burroughs have a vast and varied experience across engineering disciplines with great knowledge of timber performance. Following the successful award of funding, Burroughs were appointed to support the project as consultant engineers. Their principal role has been to measure the structural performance of the Ty Unnos components and to develop an understanding of its unconventional structure through computer modelling, prototyping and physical testing. They have also taken a lead role in the management of information gathering and production for the certification of the Ty Unnos components and derivative systems.

Chapter 2.0

Affordable Housing for Rural Wales

a study of the context of providing affordable housing for rural Wales

2.01 INTRODUCTION

In the following chapter, a need will be established for affordable housing in rural Wales. This will begin with an analysis of policy, which will define the context of affordable housing and what is considered to be ‘Rural Wales’. Through the study of published data and research studies, this analysis will also identify the scale and nature of the housing need. A review of government strategy and planning policy will identify the primary mechanisms currently employed to facilitate and encourage delivery of affordable homes in rural Wales. With this context, finally an examination of international and national precedents will inform a proposal for the use of self build as an alternative mechanism for the delivery of affordable housing in rural Wales.

Over the last two decades, rural Wales has witnessed a significant increase in population, with a net increase of 50,300 people in the period 1991-2001.¹ However this masks a dramatically changing demographic, with rural areas recording net out-migration of people in the age range of 15-29 years in 2000-01.² This has resulted in an aging rural population, with 20% of the population recorded as over 65 years compared with 16% in urban areas.³ A study conducted by the Wales Rural Observatory (WRO) in 2005 to consider the presence of poverty and social exclusion in rural Wales found that 64% of respondents in low income households were aged 55 years or over, compared with 44% for Wales as a whole.

In addition to significant demographic and population changes, the economic structure of rural Wales has also dramatically altered during this period. In general, the economy has become more akin to the rest of Wales, with a decline in the importance of agriculture and growth of the service sector, to employ 6% and 69% respectively.⁴

A comparison of average incomes is deceptive. Rural areas of Wales display an average of £26,803 per annum, just less than the average for Wales of £27,328. However, 8 out of 9 rural authority areas were found to have average incomes below the national mean. The WRO 2005 survey also found that one quarter of 4000 households surveyed were living on incomes of less than £10,000, a finding reinforced by a review of paycheck data in 2003 that found that 20% of working households in rural areas had an income of less than £10,000.⁵

Although these levels of income and low income households are comparable with the national average, house prices have risen dramatically in rural areas to

1 Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008), p. 8.
2 Ibid., p. 8.
3 Ibid., p. 8.
4 Ibid., p. 9.
5 Ibid., p. 10.

an average price of £155,000, 12% higher than the national average. Between 1997 and 2005 rural house prices have increased by 176%, a significant increase over the national average rise of 157%.⁶

Subsequently homelessness has become a critical problem, far beyond the levels concerning urban areas of Wales. Figures provided by the WRO in 2006 show that households considered as homeless and in priority need rose by 309% in rural authorities, compared with a rise of 129% in urban authority areas. This rise has been acute over the last decade rising from 1226 in 1997-98 to a peak of 3595 in 2004-05 before settling back to 2249. A rise of 83% over 1997-98 figures, compared with an increased of 34% in the same period for urban areas.⁷

These levels of rises have put dramatic pressure on the need for greater availability of affordable housing both in open market conditions and through government mechanisms of subsidy.

In 2007 the Welsh Assembly Government (WAG) published its One Wales agenda. Within this policy the Assembly made a number of proposals to ease housing pressure, including the commitment to increase the supply of affordable housing by at least 6,500 homes over the period 2007/8 to 2010/11. The agenda highlighted a series of guidance and policy interventions, an increase in the availability of publicly owned land and a greater flexibility to identify sites solely for affordable housing purposes in order to achieve this target.

Just one year later in 2008 the Joseph Rowntree Foundation (JRF), based on previous research by the Welsh Royal Observatory, delivered an acute assessment, with the publication of *Rural Housing in Wales*. Although largely commending the commitment identified by the One Wales agenda, the publication proposed a number of recommendations that it felt the WAG must address in order to meet the commitment.

The research period has paralleled a period of significant strategic and procedural change in the delivery of affordable housing in Wales. The review of policy and guidance was performed early in the research period in order to provide an understanding of the subject context. It has not been beneficial to the delivery of the research objectives to continuously revise my understanding of current policy and guidance throughout this period, therefore it is likely that some of the detail may now require revision.

6 Ibid., p. 12.

7 Ibid., p. 16.

2.02 WHAT IS AFFORDABLE HOUSING?

*the concept of affordability is generally defined as the ability of households or potential households to purchase or rent property that satisfies the needs of the household without subsidy.*⁸

Under planning policy in Wales, ‘Affordable Housing’ is defined as housing where secure mechanisms are in place to ensure accessibility to those whose needs cannot be met by open market housing due to affordability.⁹ This objective is extended beyond first occupation to subsequent occupiers in the dwelling’s whole life cycle. Secure mechanisms include regulation of rents and prices, control and management of applicable tenants, and identification of housing need. This also includes enforcing the reinvestment and recycling of funds into replacement affordable housing when homes cease to be affordable or ‘staircasing to full ownership’ is desirable.

Affordable housing can be broken down into two sub-categories;

- Social rented housing- is provided by Local Authorities (LAs) or Registered Social Landlords (RSLs). In Wales this is predominantly in the form of Housing Associations (HAs), who are independent, not-for-profit organisations, registered and regulated by WAG. Rent levels must be reflective of rent benchmark guidance determined by the ‘Regulatory Code for Housing Associations in Wales’, and guideline rents that are calculated by individual LAs based on statistical analysis.¹⁰
- Intermediate housing- is aimed at rents or prices above those of social rented housing but below local market rents or prices. It includes equity sharing schemes, such as Homebuy, operated by RSLs to enable existing social housing tenants or those on housing waiting lists to purchase a home with an interest-free equity loan.¹¹

Affordability is generally assessed as a ratio of household income to the average price of the required property type to buy or rent in the local open housing market. The Local Housing Market Assessment Guide suggests that a property purchase can be assessed as affordable if within a ratio of 3.5 times the gross household income for single earner households and 2.9 times for dual earner households.¹² The guide also suggests that up to 25% of gross household income should be considered affordable for rented accommodation.¹³

8 Welsh Assembly Government, *Planning Policy Wales: Technical Advice Note 2: Planning And Affordable Housing* (Cardiff: Welsh Assembly Government, 2006), p. 2.

9 Ibid., p. 4.

10 Ibid., p. 4.

11 Ibid., p. 4.

12 Welsh Assembly Government, *Local Housing Market Assessment Guide* (Cardiff: Welsh Assembly Government, 2006), p. 64

13 Ibid., p. 64.

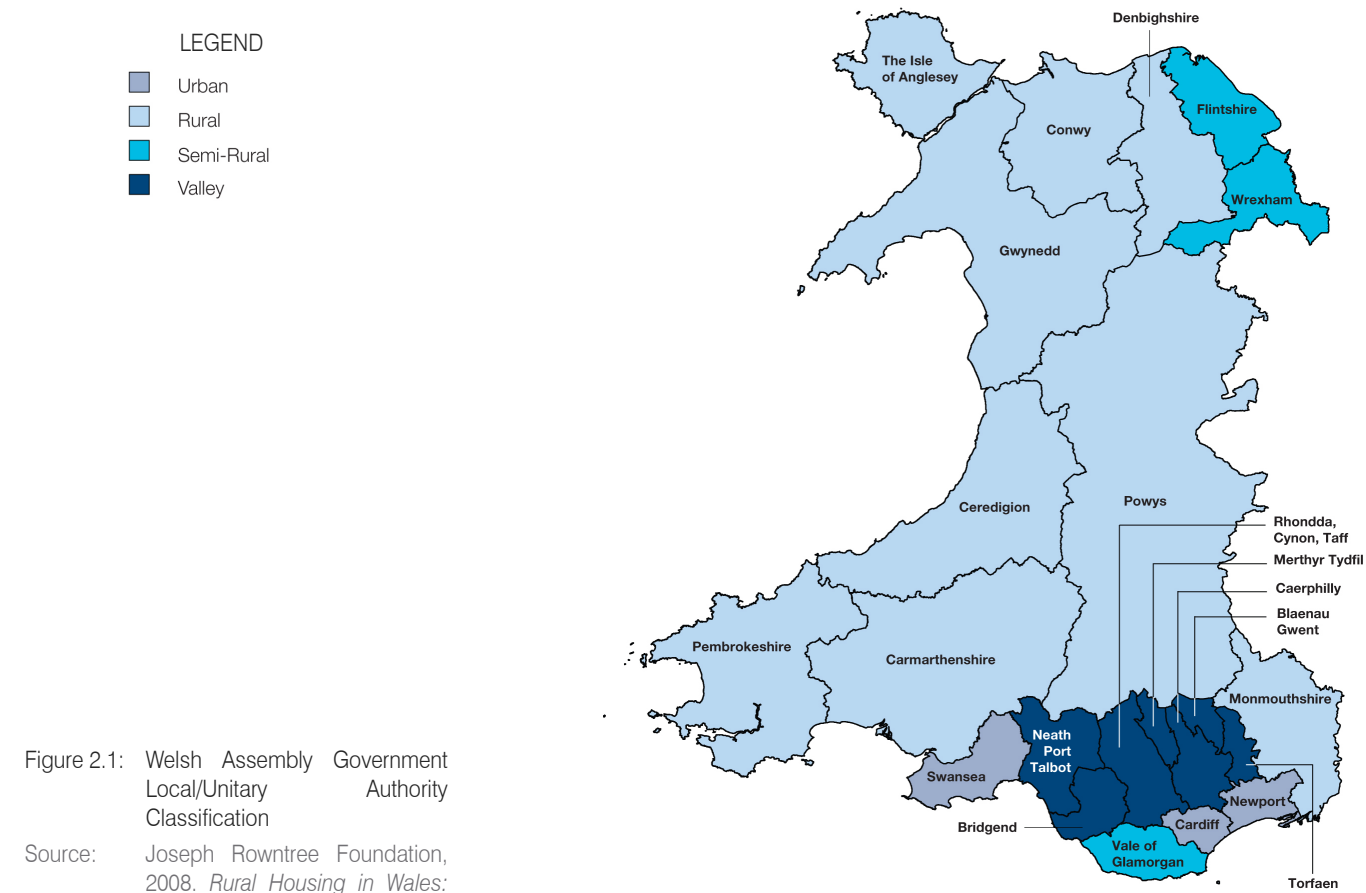


Figure 2.1: Welsh Assembly Government Local/Unitary Authority Classification

Source: Joseph Rowntree Foundation, 2008. *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008), p. 8.

2.03 DEFINING RURAL WALES

Wales is incredibly diverse in its economic, cultural, demographic and geographic representation. The term Rural Wales is applied quite commonly in the consideration of housing and the economy of Wales however it needs a clear definition in order to establish its boundaries. The Wales Rural Observatory (WRO), a WAG funded team of specialist researchers established in 2003 to undertake independent research and analysis of social and economic issues to support policy making for rural Wales, recognise a number of classification systems for the identification of ‘Rural Wales’. These include;

- The WAG Unitary Authority System
- The Office for National Statistics Urban Rural Classification
- The Rural Development Plan for Wales 2007 - 2013

For the purpose of this study, the WAG Unitary Authority System of ‘Rural’ authorities will be employed to define ‘Rural Wales’. This is a four-tier classification system applied to define Rural Wales based on data that is available at a Unitary Authority level. The four tiers are described as Rural, Semi Rural, Urban and Valley Authorities. The Rural class includes 9 Local Authorities; The Isle of Anglesey, Gwynedd, Conwy, Denbighshire, Powys, Ceredigion, Pembrokeshire, Carmarthenshire and Monmouthshire. The 2001 Census of Population shows that 959,486 people lived within the nine rural authority areas, accounting for 33% of the Welsh population. A further 396,362 people live within the semi-rural authorities of Flintshire, Vale of Glamorgan and Wrexham.¹⁴

Within this classification however there remains significant economic and social diversity.

2.04 AFFORDABLE HOUSING IN WALES

The 2001 Better Homes for People in Wales identifies the WAG’s housing strategy as;

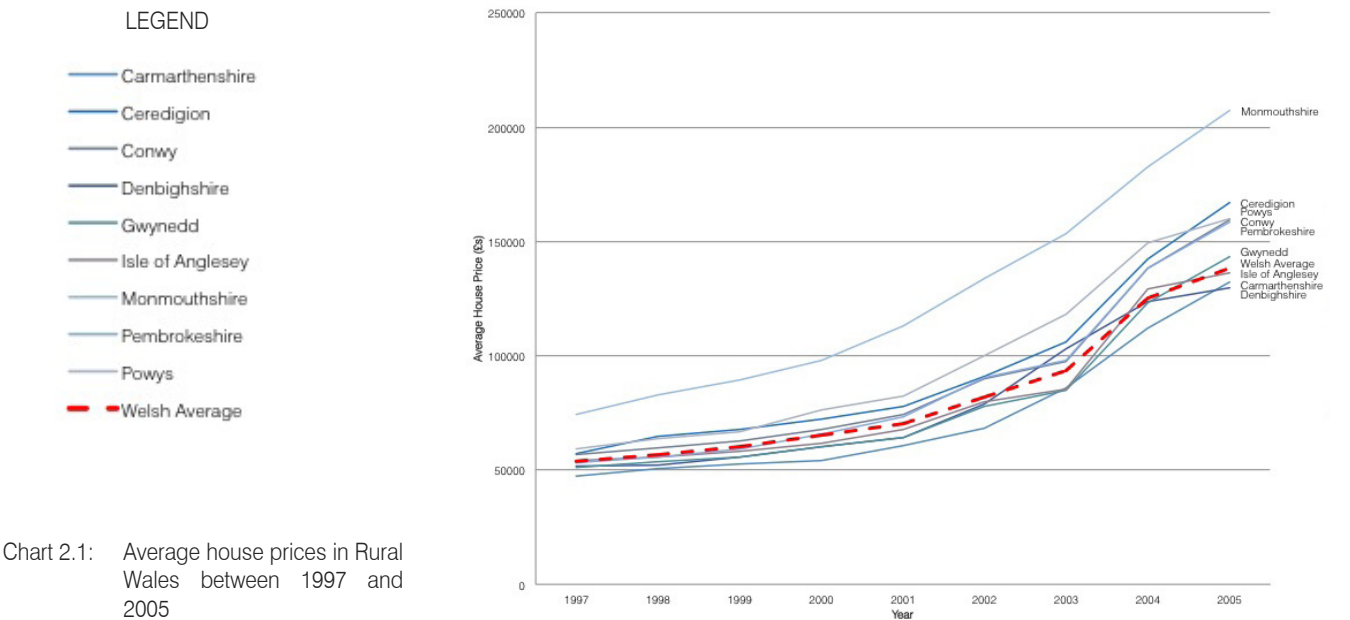
‘We want everyone in Wales to have the opportunity to live in good quality, affordable housing; to be able to choose where they live and decide whether buying or renting is best for them and their families.’¹⁵

2.04.1 AFFORDABLE HOUSING NEED IN RURAL WALES

In 2006 the WRO published a study looking at the nature, scale and geography of housing need in Rural Wales. The study is based on national statistics such as the 2001 census, and data collected through local studies.¹⁶ In June 2008, this data was supplemented by a report produced by the JRF Commission on *Rural Housing in Wales*. The report based considerable analysis on the WRO data set and incorporated a larger field of data from a number of additional sources to establish the need for housing in rural Wales, with the result being a series of recommendations for policy and practice change.

As a measure of affordability, two data sets are relevant, firstly the average property price, and secondly an average income to average house price ratio. Based on land registry data sets, the following conclusions can be drawn for the nine rural wards,¹⁷

- Between 1997 and 2005 average property prices have increased by 176%
- Between 2001 and 2005 these prices have doubled from £75,308 to £154,886



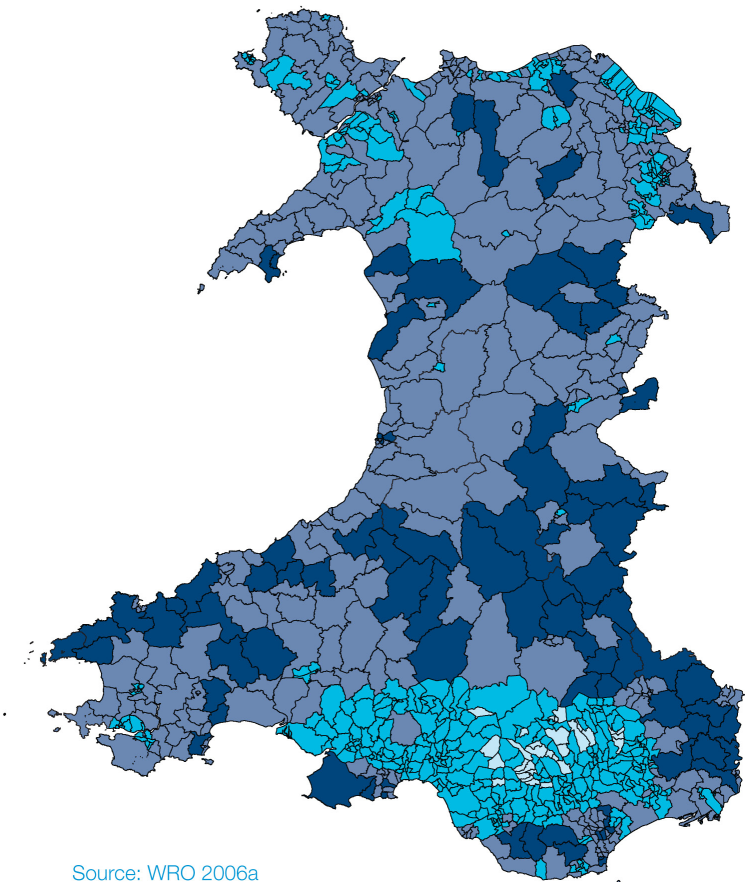
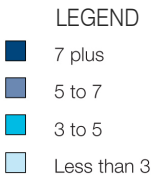
15 The National Assembly for Wales, *Better Homes for People in Wales : A National Housing Strategy for Wales* (Cardiff: National Assembly for Wales, 2001), p. 8.

16 Lawrence Kitchen and Paul Milbourne, *Housing Need in rural Wales : towards sustainable solutions* (Cardiff: Wales Rural Observatory, 2006), p. 3.

17 Ibid., p. 23.

Figure 2.2: Average house price to average household earned income ratio by ward in Wales 2005

Source: Joseph Rowntree Foundation, 2008. *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008), p. 15.



Source: WRO 2006a

Unitary Authority	Category		Mean House Price (£)	Mean Income (£)	Affordability
Carmarthenshire	Rural		133 639	26 136	5.11
Ceredigion	Rural		164 586	25 628	6.42
Conwy	Rural		149 901	26 313	5.70
Denbighshire	Rural		151 900	28 107	5.40
Gwynedd	Rural		138 355	25 126	5.51
Isle of Anglesey	Rural		136 340	25 920	5.26
Monmouthshire	Rural		228 026	33 234	6.86
Pembrokeshire	Rural		152 986	25 591	5.98
Powys	Rural		179 370	27 105	6.62
	Rural		158 662	26 803	5.92
	Wales		143 810	27 328	5.26

Table 2.1: Average house price, income and affordability for rural authorities in 2003
Source: Lawrence Kitchen and Paul Milbourne, *Housing Need in rural Wales : towards sustainable solutions* (Cardiff: Wales Rural Observatory, 2006), p. 28.

- This is considerably higher than the national average, which recorded an increase of 157% in the period 1997 - 2005.
- The average property price in rural Wales in 2005 was £155 000, 12% higher than the national average.

The WRO study found that based on data collected by CACI in 2005,¹⁸

- The ratio of average house price divided by average household income for the nine rural authorities has increased dramatically from 2003 to 2005, rising from an average of 4.21 to 5.92.
- The rural average of 5.92 is 12% higher than the national average of 5.26
- Carmarthenshire is the only rural authority to record an affordability ratio of less than the national average.

The JRF report expands on this assessment using data collected from property transactions by HBOS in 2007. The HBOS analysis is based on estimated local earnings for full time males and suggests that all nine rural authorities had a ratio exceeding 5.0 in 2007.¹⁹ When considered against the Local Housing Market Assessment Guide recommendation of 3.5 times the gross household income for single earner households and 2.9 times for dual earner households, this

18 Ibid., pp. 27 - 31.

19 Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report*, p. 13.

displays an acute level of unaffordability.²⁰

In the 11 year period 1996-97 to 2006, 31,384 new homes were constructed in the nine rural LA areas, accounting for 2,853 homes per year. Of this figure 91% of all new completions were in private ownership, with 2,865 new properties provided by RSLs and just 36 new properties completed by LAs.²¹ In comparison the JRF report suggests a total of 10,217 property sales from the LA housing stock in the same time period under the Right-to-Buy scheme - over three times as many as were constructed.²² In addition, recent data shows that the number of homeless households has risen by 83% in rural Wales between 1997-98 and 2006-07. This is dramatically higher than the corresponding 34% increase in urban areas of Wales.²³

The JRF and WRO reports employ the statistical findings of affordable housing needs assessments carried out between 2000 and 2004 using, in most cases, the OPDM Basic Needs Assessment Model. This models need against supply to calculate the net shortfall or surplus of affordable housing units per annum by LA area. Table 2.3 shows the findings of these assessments. The study suggests a total shortfall of 3,803 affordable properties per annum across rural Wales. The JRF report also highlights the analysis of LA housing waiting lists as a reflection, if somewhat limited, of the housing needs in rural Wales. The nine LA housing lists in 2006 showed a total of 25,000 households awaiting housing.²⁴ This figure does not however include households where a suitable property can not be identified from the existing LA stock, i.e. four bed households or housing for single occupancy.

Table 2.2: Profile of the Housing Stock of Rural Wales in 2001

Type	Rural Wales	Wales
Private Sector -		
Owner Occupied	71%	71%
Rented	10%	7%
Social Housing -		
Local Authority	12%	14%
Housing Association	4.1%	7%
Vacant Properties	4.1%	4%

Table 2.3: Net shortfalls of Affordable Housing per annum by local authority areas

Source: Joseph Rowntree Foundation, 2008. *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008), p. 17.

Local Authority	Assessment Model	Year	Net Shortfall per annum
Carmarthenshire		2000	459
Ceredigion	BNAM	2004	274
Conwy	BNAM	2002	209
Denbighshire	BNAM	2003	645
Gwynedd		2002	314
Isle of Anglesey	BNAM	2001	311
Monmouthshire		2000	916
Pembrokeshire		2000	358
Powys	BNAM	2002	317
Total Shortfall			3803

20 Welsh Assembly Government, *Local Housing Market Assessment Guide*, p. 64.

21 Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report*, p. 11.

22 Ibid., p. 11.

23 Ibid., p. 16.

24 Ibid., p. 15.

2.05 AFFORDABLE HOUSING POLICY IN WALES

The WAG is directly responsible for the strategy and delivery of affordable housing in Wales. The national strategy for affordable housing is set out in two key documents; the 2007 *One Wales* agreement, and Wales' first National Housing Strategy *Better Homes for People in Wales* published in 2001, which is currently under review. The WAG identifies its role in the provision of affordable housing as;

- The allocation of housing resources to LAs and to HAs in Wales, and the overseeing of their activities;
- The oversight and regulation of the activities of Registered Social Landlords in Wales, and of the private rented sector;
- The provision of housing in Wales for those with support needs.

2.05.1 THE ONE WALES STRATEGY

In 2007 the WAG published its *One Wales* agenda. Within this policy the Assembly has made a number of proposals and commitments to ease housing pressure under *Chapter 5 Living Communities*. This includes improved guidance and policy interventions, increased availability of publicly owned land and greater flexibility to identify sites solely for affordable housing purposes.

Most critically the strategy identifies a commitment to increase the supply of affordable housing by at least 6,500 homes over the period 2007/8 to 2010/11.²⁵

To accompany the strategy, the WAG published the One Wales Delivery Plan 2007-2011. This provides detailed information on the delivery of the strategy including key Milestones and monitoring measures. It also identifies a series of key measures to deliver the target housing number, including;²⁶

- Increased implementation of Section 106 agreements,
- An update to the *Land Disposal Protocol* to improve the release of publicly owned land at below market values,
- Revise guidance documents to prioritise the provision of 100% affordable housing sites, in addition to planning policy requirements for percentage provision of affordable housing on development sites,
- A dedicated budget of £100k per annum to invest in the development of the Community Land Trusts including a budget for The Land for People organisation and a new Rural Housing Development Fund.

25 Welsh Assembly Government, *One Wales Delivery Plan 2007-2011* (Cardiff: Welsh Assembly Government, 2007), p. 24.

26 Ibid., pp. 25 - 27.

2.06 MECHANISMS FOR DELIVERING AFFORDABLE HOUSING IN WALES

2.06.1 FUNDING MECHANISMS INCLUDING THE SOCIAL HOUSING GRANT

In addition to securing private development finance, there are a limited number of funding mechanisms available to Registered Social Landlords (RSLs) in order to finance the construction of affordable housing. Typically in Wales these include;

- SOCIAL HOUSING GRANT (SHG)

A capital grant made available to RSLs by the WAG to fund approximately 58% of the total cost of affordable housing, with the remainder of the costs funded through private finance and recycled assets. The total cost includes; land purchase price, construction works, VAT and oncosts.

In order to be eligible for SHG, schemes must comply with the WAG’s Acceptable Cost Guidelines, Design Quality Requirements, Lifetime Homes and the Welsh Housing Quality Standards.

Since 2004, the WAG has committed to a significant increase in SHG allocation, rising from £76.4 million in 05/06 to £106.9 million in 2008/09.²⁷However the economic downturn has resulted in a significant drop in the SHG budget for 2011-2012, falling to £69.2 million.
- SECTION 106 AGREEMENTS (S106)
- RECYCLED CAPITAL GRANT (RCG)

An internal fund held within the accounts of an RSL in order to recycle previously allocated SHG which has become available through the sale of land or housing from the RSL’s portfolio.

In the period 2007-08 and 2008-09 Statistics for Wales Bulletin 38/2010 states that a total of 4,235 additional affordable housing units were constructed in Wales.²⁸ 50% of these units were delivered by RSLs using capital grant funding including SHG, RCG and Strategic Capital Investment Fund (SCIF). However in rural Wales the proportion of units delivered using SHG is considerably higher with 8 of the 9 rural authorities delivering over 80% of units using SHG.²⁹

In the same period, 1,156 units or 27% of the total affordable housing units constructed in Wales were delivered using planning obligations typically in the form of Section 106 agreements.³⁰

27 Welsh Assembly Government, *Social Housing Grant allocations*, (Cardiff: Welsh Assembly Government, 2007)
<<http://wales.gov.uk/topics/housingandcommunity/housing/publications/shgallocations/?lang=en>> [accessed 10 Sep 2010]

28 Statistics for Wales, *Statistical Bulletin 38/2010 : Affordable Housing Provision in Wales, 2007-08 and 2008-09* (Cardiff: Welsh Assembly Government, 2010), p. 1.

29 Ibid., p. 1.

30 Ibid., p. 1.

2.06.2 SECTION 106 AGREEMENTS AND SITE THRESHOLD LIMITS

Section 106 of the Town and Country Planning Act 1990 allows for a Local Planning Authority and a developer or landowner to enter into a legally binding agreement in association with the granting of planning permission.³¹ The nature of the agreement is determined on a site by site basis by LAs in line with established policy, case study precedent and negotiation, and it has become an increasingly important mechanism for delivering affordable housing.³²

Planning obligations negotiated under a S106 must be directly related to the proposed development, and be considered fair, reasonably scaled, and necessary, in order for an agreement to be acceptable in planning terms.³³ The Affordable Housing Toolkit states that the most common form of subsidy is the provision of land at discounted values however agreements are also used to supply fully constructed dwellings for affordable housing purposes.³⁴

The structure and model of S106 agreements are established by individual Local Authorities within the LDP in two forms,

- Site Capacity Thresholds - applied either to the authority area as a whole or as a range of thresholds across the plan area.³⁵ Above the threshold, proposals are required to incorporate a percentage of affordable housing units. For example the Supplementary Planning Guidance published by Carmarthenshire applies a requirement for 25% or 35% of the number of homes on the site dependent on postcode area,³⁶ whilst the Conwy AHDS places a minimum requirement of 50% for all housing developments.³⁷
- Site Specific Targets - are given for sites identified within the LDP which have an element of residential use, either in the form of an authority wide target, identified area target or in some cases as targets for specific individual sites.³⁸ Targets are typically considered as a starting points for negotiation and often seen as a value below which planning authorities should seek commuted sums using a S106 Agreement.³⁹

Both targets are generated at a local level by extrapolating authority wide targets and applying to known and potential development opportunities on a site by

31 Steven Rowley and others, *Wales Planning Research Programme : The Use and Value of Planning Obligations in Wales* (Cardiff: Welsh Assembly Government, 2007), p. 3.

32 Welsh Assembly Government, *The Affordable Housing Toolkit* (Cardiff: Welsh Assembly Government, 2006), p. 22.

33 Steven Rowley and others, p. 4.

34 Ibid., p. 4.

35 Welsh Assembly Government, *Delivering affordable housing using section 106 agreements: Practice Guidance* (Cardiff: Welsh Assembly Government, 2008), p. 9.

36 Ibid., p. 12.

37 Conwy County Borough Council, p. 13.

38 Welsh Assembly Government, *TAN 2: Planning And Affordable Housing*, p. 9.

39 Welsh Assembly Government, *Changes to Rural Planning Policy: Planning Policy Wales: Edition 3* (Cardiff: Welsh Assembly Government, 2010), p. 5.

site basis.⁴⁰ However these affordable housing targets are generally considered indicative and there is an element of negotiation associated with the policy to ensure that appropriate targets are applied.⁴¹

“the strong presumption is that affordable housing secured through planning obligations will be provided on the application site so that it contributes to the development of socially mixed communities.”⁴²

In most cases the resultant planning obligation is an appropriate provision of land on the development site for the construction of affordable housing units, or the provision of completed units on the development site.⁴³ The policy recognises however that there are scenarios where this is not appropriate, and alternative contributions may be considered, including financial contributions in lieu for the construction of a 100% affordable housing development.⁴⁴

2.06.3 DISPOSAL OF PUBLICLY OWNED LAND

Within the One Wales strategy the WAG make the explicit commitment to release publicly owned land at below market value.⁴⁵ Legally this is enabled by the Local Government Act 1972: General Disposal Consent (Wales) 2003 which empowers LAs to dispose of land at 'less than best consideration' without requiring the consent of the WAG. In order for this to be considered applicable the disposal must;

*Contribute to the promotion or improvement of the economic, social or environmental well being of its area, or all or any persons resident or present in its area and the undervalue does not exceed £2 million.*⁴⁶

It is intended that the increased availability of public land at a discount below market value will improve the economic viability of schemes for interested parties including organisations such as Community Land Trusts, whilst reducing the demand on SHG. See Figure 2.3.

2.06.4 COMMUNITY LAND TRUSTS

A Community Land Trust (CLT) is defined as a not-for-profit community organisation that owns, develops and manages land and buildings for the benefit of the local community.⁴⁷ The structure and responsibilities of CLTs vary widely between organisations, adapting according to local needs and resources, however they share the principal objective of acquiring land and property to be held in trust to meet the needs of the local community. This is often achieved by

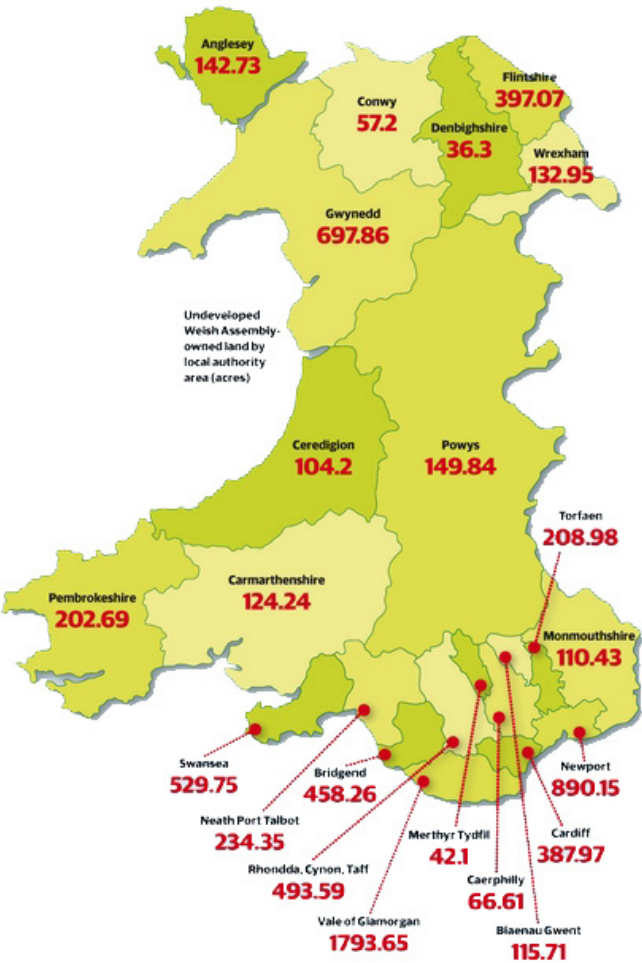


Figure 2.3: Undeveloped Welsh Assembly owned land by local authority area (acres)
Source : Caroline Thorpe, *From valley to vale* (insidehousing.co.uk, 2011) <www.insidehousing.co.uk/development/from-valley-to-vale/6517090.articlen> [accessed 10 Jun 2012]

40 Welsh Assembly Government, *TAN 2: Planning And Affordable Housing*, p. 8.
41 Ibid., p. 10.
42 Ibid., p. 13.
43 Welsh Assembly Government, *The Affordable Housing Toolkit*, p. 22.
44 Welsh Assembly Government, *TAN 2: Planning And Affordable Housing*, p. 13.
45 Welsh Assembly Government, *One Wales Delivery Plan 2007-2011*, p. 26.
46 Welsh Assembly Government, *The Affordable Housing Toolkit*, p. 24.
47 National Assembly for Wales, *Members' Research Service : Quick Guide : Community Land Trusts* (Cardiff: National Assembly for Wales, 2010), p. 1.

separating the value of land assets from the value of the properties that stand on it, enabling property and development costs to be reduced whilst locking in the value of the land asset as a valuable community asset in perpetuity, including the gain resulting from permission to develop and land appreciation.⁴⁸

Following models developed in Scotland and the USA, CLTs are recognised as a valuable mechanism for delivering affordable housing specifically in rural communities. As previously mentioned the WAG has shown increased support for the development of CLTs in Wales within the One Wales Strategy, with the financial commitment of £100,000 per annum to assist their development.⁴⁹ This includes a budget for Land for People, a not-for-profit organisation which works with communities in Wales and the Marches to help build affordable homes for local people.⁵⁰

CLTs can make use of a number of previously described mechanisms to acquire land. The Community Land Trust Handbook produced by Land for Good in 2010, describes a series of CLT case studies in Wales. Examples of land acquisition include;⁵¹

- The redevelopment of surplus publicly owned land, in this case from within the Forestry Commission Wales portfolio,
- The use of S106 agreements to transfer privately owned land into CLT ownership,
- Donations of land, or acquisitions of land at below market values, made available due to the intent to redevelop for the purpose of affordable housing,
- Acquisition of land, or buildings at market value with the support of grant funding.

As of 2010, there formally exists four CLTs in Wales, all operating with support from Land for People, with the first units intended for construction in 2010.⁵²

48 Ibid., p. 1.

49 Welsh Assembly Government, *One Wales Delivery Plan 2007-2011*, p. 24.

50 Land for Good, *Community Land Trusts: capturing land values for communities*. (Oswestry: Land for Good, 2010), p. 4.

51 Ibid., pp. 11 - 21.

52 National Assembly for Wales, *Members’ Research Service : Quick Guide : Community Land Trusts*, p. 3.

2.07 ADDITIONAL DELIVERY MECHANISMS FOR RURAL WALES

2.07.1 RURAL EXCEPTION SITES

Rural Exception Sites are small sites within or adjoining existing rural settlements which would otherwise not be considered for market housing, where specific need is identified for affordable housing. The guidance notes specify that the rural exception site policy is applicable only where the local need falls within the objective of delivering sustainable communities, for example, where existing households or families need separate accommodation in the area, or where employment provides essential services and there is a need for proximity to the local community. Planning obligations over Rural Exception Sites must ensure that the provision of housing will never be allowed to reach open market, but rather to set a ‘cascade’ mechanism where suitable applicants are always found for continued occupation.⁵³ This may be in the form of a geographical mechanism, prioritising local people or people that have current employment in the locality, or by prioritising needs.⁵⁴

2.07.2 RURAL HOUSING ENABLERS

Rural Housing Enablers (RHEs) are independent brokers who, in collaboration with local communities, local planning and housing authorities, RSLs and landowners, look to identify and address the housing needs of rural communities.

The Rural Housing Enabler model has proved to be an extremely successful method for addressing rural needs in England with over 40 people employed and nearly £700,000 invested by Defra in the period up to March 2006. In response to its success, Wales began its own 3 year pilot scheme in 2003 in the area of Monmouth and South Powys. A further three RHE posts were created to cover the areas of Pembrokeshire, Conwy, Denbighshire, and Gwynedd.⁵⁵

The RHE in Wales have the following objectives;

- Identify rural housing needs and contribute local data to support need, including localised housing assessments, waiting lists etc to ensure specific rural needs are promoted in rural strategies
- Assist in the identification of sites for affordable housing through community liaison exercises and direct landowner identification, encouraging the involvement of local communities in the assessment of site options to reduce animosity between communities and developers
- Identify and liaise with organisations who may be able to assist in the

53 Welsh Assembly Government, *TAN 2 : Planning And Affordable Housing*, p. 11.
54 Ibid., p. 14.
55 Helen Cook, *Delivering Rural Affordable Housing : WAG Seminar on housing planning policy* (presentation, 2009), slide 2.

provision of affordable housing and create awareness of housing issues throughout the community

- Act as an independent broker throughout the process to help advise and negotiate compromises to maintain progress.

Following the positive conclusion of the pilot scheme, the WAG extended the scheme to include a network of 10 posts across rural Wales, see Figure 2.4.

Figure 2.4: Rural Housing Enablers operating in Wales
Source : Rural Housing Enabler, *Rural Housing Enablers in Wales*, <<http://www.rhewales.co.uk/contact.html>> [accessed 10 Mar 2010]



2.08 BARRIERS TO THE DELIVERY OF AFFORDABLE HOUSING IN RURAL WALES

In December 2008 The Centre for Regional Economic and Social Research (CEREA), Sheffield Hallam University, was commissioned by the WAG to carry out a study to identify the barriers to the delivery of affordable housing specifically in the context of rural Wales.⁵⁶ The intention of the study, as part of the Wales Planning Policy Development Programme, is to provide evidence based guidance for the development of future planning policy.

The CEREA was therefore asked to examine existing policy documents and research evidence, and through consultations, interviews, and case studies, identify the key barriers and enabling factors in the delivery of affordable housing.

The report, published in August 2009, identifies a broad range of barriers advising that delivery is generally affected by a combination of barriers rather than any singular cause.⁵⁷ These barriers restrict the emergence of potential projects but can also severely limit the success of developing projects including those that have secured planning permission and may result in projects being terminated, placed on hold or significantly delayed.

The report identified the following as key development barriers;

- Land availability and price due to a limited knowledge of development sites, the reluctance of landowners to sell, often due to unrealistically high valuations, the restrictive nature of existing development boundaries and a general failure to bring identified land to market,⁵⁸
- The appropriateness of potential land for development, in particular the economic viability of development sites. Small, rural sites are often found to be challenging in terms of access, drainage, services, ground works, design and materiality, and lower economies of scale resulting in higher construction costs,⁵⁹
- High house price to income ratios, which in some specific areas have been exacerbated by second and holiday homes,⁶⁰
- A long term reduction to SHG and Acceptable Cost Guidance,
- The limited resources available to undertake fine grained analysis of current and future housing need at an individual settlement level has resulted in housing need being hidden from identification and an absence

56 John Flint and others, *A Study to Examine Local Barriers to the Delivery of Affordable Housing in Rural Wales : A Report to the Welsh Assembly Government* (Sheffield: Centre for Regional Economic and Social Research Sheffield Hallam University, 2009), p. 2.

57 Ibid., p. 28.

58 Ibid., p. 29.

59 Ibid., p. 30.

60 Ibid., p. 28.

of data on the types of properties and tenure required,⁶¹

- The role and appropriateness of developers, specifically a reliance on small local developers who have reduced financial capacity and ability to future plan.⁶²

The study identified a number of barriers directly associated with planning policy and delivery mechanisms such as S106 agreements and rural exception sites;

- Many of the rural sites identified for development do not meet local size thresholds and enforcement of affordable housing quotas can often render small scale developments economically unviable,⁶³
- A lack of model agreements or precedents result in a tendency to take a case by case approach to development sites, often requiring extensive negotiation between parties and resulting in considerable inconsistencies and uncertainty between projects,⁶⁴
- Tensions between planning policies often generate conflicting priorities, for example the need for affordable housing and environmental protection,⁶⁵
- A number of policies are seen as imposing restrictive criteria or definitions that limit their applicability.

A primary theme within the study is the role of local communities, councillors and planning authorities in the delivery of affordable housing. The report employs the term nimbyism to describe the opposition posed by local parties to affordable housing proposals and the stigmatism associated with social housing. Local opposition is a critical and complex barrier to development, often linked to the historical context of the community, the attitude taken to local needs and tenure types, the scale of development and the design approach taken. However the report also identifies the power associated with positive support from the community and the ability for opposition to be turned into an enabling factor through a connected approach to development.

The research study was performed during the developing economic downturn, it therefore reflects on the barriers associated with the turbulent financial climate. In general the economic downturn has simply exacerbated many of the existing barriers with landowners reluctant to sell at falling prices, developers moth balling development sites or attempting to renegotiate S106 agreements, and significantly reduced finance options for all parties involved. The result has been a “*general stalling of development*”.⁶⁶

61 Ibid., p. 31.
62 Ibid., p. 32.
63 Ibid., p. 34.
64 Ibid., p. 34.
65 Ibid., p. 31.
66 Ibid., p. 35.

2.09 SELF BUILD AS A DELIVERY MECHANISM

The delivery of housing in the UK is heavily dependent on volume housebuilders. The Calcutt review published in 2007 estimates that just 12 house building companies were responsible for delivering 44% of house completions in the UK between 2000 and 2005.⁶⁷ The National Self Build Association (NaSBA) report 3 companies; Taylor Wimpey, Barratt/Wilson Bowden and Persimmon are responsible for delivering between 15,000 to 20,000 homes per year each, approximately 8 to 12% of all house completions in the UK.⁶⁸ Consequently, many of the mechanisms available to the government and local authorities through the planning system are directed at obligating volume housebuilders to support the delivery of non open market housing as 'Affordable Housing' units. This reliance on volume housebuilders is more significant in the UK than is typical in many other European nations and makes the UK significantly reliant on commercially driven organisations to deliver essential and often acute local social and economic needs. Subsequently it has left the supply of 'Affordable housing' in the UK highly susceptible to market forces. The current economic downturn has resulted in a significant decline in new open market house completions and subsequently the supply of affordable housing has also been significantly affected.

Self build offers a distinctly alternative and independent route of procurement for new build housing. The NaSBA report 'Self Build as a Volume Housebuilding Solution' offers a comprehensive overview of the existing self build market in the UK and suggests a number of measures that could be introduced by the industry and government to expand the sector. The report, published in 2008, states that self builders are responsible for delivering approximately 20,000, or 12% of new homes.⁶⁹ The sector is however considerably less developed than many other countries, with some delivering over 50% of new homes through self build methods, see Chart 2.2.

2.09.1 INTERNATIONAL APPROACHES TO SELF BUILD

FRANCE

Local mayors are given capacity to purchase edge of settlement sites, particularly in rural areas, to sell on to local people at relatively low cost for self builders. The sale of plots easily covers the initial purchase price of land and the provision of services and infrastructure.⁷⁰

67 Home Builders Federation, *Calcutt Review Of Housebuilding Delivery : Submission By Home Builders Federation (HBF)* (London: Home Builders Federation, 2007), p. 17.

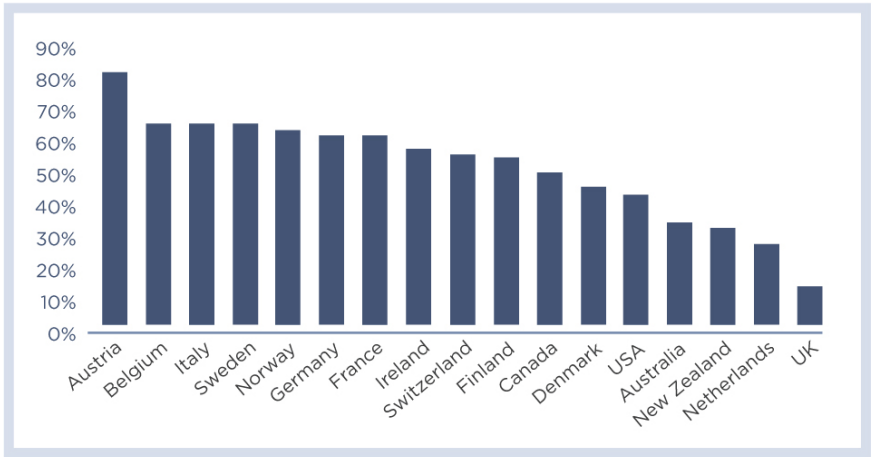
68 National Self Build Association, *Self Build as a volume house building solution* (London: National Self Build Association, 2008), p. 8.

69 Ibid., p. 8.

70 Ibid., p. 10.

Chart 2.2: Proportion of new homes constructed using self build methods

Source : National Self Build Association, *Self Build as a volume house building solution* (London: National Self Build Association, 2008), p. 8.



GERMANY

A commonly reported example is the Vauban project, a new town development which has given priority to allocating small plots of land to self builders and approximately 30 community self build groups. Buergerbau, a community organisation, has been created to coordinate and support building cooperatives consisting of 5 to 20 households in the selection of land and the appointment of a collective design and construction team.⁷¹ The city has established a basic specification of ecological standards for the development and a principle of “Learning while Planning” which has enabled citizens to participate in the planning process.⁷²

NETHERLANDS

Land within developments is commonly allocated and zoned as self build during master planning. An example is a 100ha self build zone in the south western Homeruskwartier district of the new town Almere. Self build plots have been organised into street plans and made available at a standard commercial cost by the Local Authorities without any further planning restrictions.⁷³

UNITED STATES OF AMERICA

It is common practice for self build plots to be readily available as elements of developer housing estates. Potential homeowners will commonly select and purchase land in a similar manner to home searches. Self builders will then often select a building ‘kit’ home from a variety of construction types and standard house patterns, for construction as a full turn-key design and construction package.



Figure 2.5: A mixture of units surrounding a car free communal landscape, Vauban, Freiburg

Source : <<http://www.stevemelia.co.uk/images/cfareas/Vauban%2010029.JPG>>



Figure 2.6: Self build units in the Homeruskwartier district, Almere.

Source <<http://gellersworldtravel.blogspot.co.uk/2012/04/amsterdam-to.html>>

71 Ibid., p. 11.

72 National Self Build Association, *An Action Plan to Promote the Growth of Self Build Housing* (London: National Self Build Association, 2011), p. 7.

73 Ibid., p. 7.

2.09.2 UK SELF BUILD PRECEDENTS

ASHLEY VALE, BRISTOL



Ashley Vale Action Group is a not for profit company formed by a group of local residents concerned about the potential redevelopment of a local brownfield site by a large developer. The group purchased the 2.1ha former scaffolding site in May 2001 with the intention of making available 20 self build plots and six 'self finish' Housing Association units.⁷⁴ The final development phase, the conversion of an existing office building into six self finish flats, was completed in 2009, completing a development of 41 self build or self finish units, 3 work units and a large community space. The initial serviced self build plots were made available for £35,000 per unit and renewable energy sources including photovoltaics, solar hot water panels and biomass are employed throughout the development.⁷⁵

DIGGERS AND HEDGEHOG SELF-BUILD PROJECTS, BRIGHTON



Two self build projects in Brighton led by architects Architype, offer a unique and pioneering approach to meeting housing need. The Diggers self build project is a group of five families and four single people who wanted to use self build to resolve their own housing need. The group, working closely with Architype throughout the project, realised 9 individual and energy efficient homes on a derelict and heavily sloping former golf course purchased from the local council. The project is a pilot study to suggest alternative and imaginative methods for making use of the SHG. Each member of the group contributed 24 hours per week during the two year program and subsequently pay below market rent and in the event that they vacate the property they may receive a capital payment.⁷⁶



The model was repeated for the construction of the Hedgehog self build development in Brighton. Using the contacts and experience gained through the Diggers project, an initial group of four people recognised the model as the only chance of getting support to house their families. Following a period of two years spent lobbying the group secured a challenging site and developed and constructed a scheme of 10 single storey homes with Architype.



In both cases the Walter Segal timber construction method, which will be discussed in more detail later, is employed with great success. As relatively low skill levels are required to construct in this manner, the group was able to act as main contractor under the leadership of an experienced appointed site manager.

OPPOSITE PAGE

Figure 2.7: Ashley Vale Self Build, Bristol
Source : <http://designbristol.ning.com/photo/ashley-vale-self-build-st>

Figure 2.8: Long view of Diggers self build project, Brighton.

Figure 2.9: View of Diggers self build project, Brighton.

Figure 2.10: Interior of a unit at Diggers, Brighton.

Figure 2.11: A detached unit from the Hedgehog self build project in Brighton, showing the suspended timber floor constructed using the Walter Segal method.

Source All : http://www.forevergreen.org.uk/Forever_Green_Ecological_Architects/Diggers_Self_Build.html

74 National Self Build Association, *Self Build as a volume house building solution*, p. 15.
75 National Self Build Association, *Self Build as a volume house building solution*, p. 15.
76 Walter Segal Self Build Trust, *Diggers, Brighton*, <<http://www.segalselfbuild.co.uk/projects/diggers.html>> [accessed 10 May 2012]

2.09.3 SELF BUILD AFFORDABLE HOUSING USING HOMEGROWN TIMBER

Following publication of the Ty Unnos feasibility study and its extensive dissemination at public events such as the Royal Welsh Show and National Eisteddfod, considerable interest has been expressed by a large number of private individuals and community groups. During this dissemination process the Project Team's experience has often paralleled the findings of the NaSBA which state;

*“Self Builder’s are often at the very cutting edge of new ideas in housing and construction”*⁷⁷

This has typically included a strong commitment to environmental and sustainable principles, but many have also displayed a great desire to actively improve the immediate challenges of local housing needs for themselves and their communities.

The initial objectives of the research project identified an intent to focus on the development of construction methods and processes that could be easily absorbed by the construction industry, making use of the existing skills and knowledge available. This was identified by the Project Team as a key priority to protect against highly skilled and over complex innovation which would meet considerable resistance from the existing industry, and severely limit the application of homegrown timber components.

During dissemination of the feasibility study, the findings were met with encouraging enthusiasm due to its intention to make use of low value, locally sourced homegrown timber. However it was the perceived simplicity and ease of assembly that appeared to capture the attention and imagination of many interested parties, including community groups.

In their report *Self Build As A Volume Housing Solution* the NaSBA describe the typical demographics of the Self Builder. The majority are described as middle or retirement age homeowners whom decide to build their dream home. Others are younger, typically associated in some manner with the construction industry and recognise the application of their skills can offer a means to an affordable home.⁷⁸

However the report also describes a very different category of self build, which are those on lower incomes who are directly affected by the acute shortage of affordable housing and see a community self build project as a method for delivering essential affordable homes to meet their own local need.⁷⁹

77 National Self Build Association, *Self Build as a volume house building solution*, p. 12.
78 Ibid., p. 6.
79 Ibid., p. 5.

The NaSBA state that there have been almost 100 of these community self build projects in the last 20 years,⁸⁰ of which the Diggers and Hedgehog self build projects are prime examples.

In these examples, each member of the group will contribute whatever skills they have to the whole development, from publicising and rallying for funding, to the physical construction of homes. Frequently groups will include individuals with existing construction skills, and often employ specialist skills where necessary. However, often, low skilled and inexperienced individuals are trained and develop skills through the construction of their own homes.

It is this element of the 'self build' industry which will be the focus of this research study. Based on precedent examples it will be assumed that although highly skilled and experienced individuals may be available in these project scenarios, many of those involved will start with a limited knowledge of construction. By setting this base standard, it is proposed that an approach to construction can be realised which will offer a solution at all skill and experience levels.

2.10 SUMMARY OF FINDINGS

Based on these findings the following can be summarised;

- There is an acute need for affordable housing in rural Wales.
- There exists considerable barriers to sustainable development in areas of rural Wales due to the availability and type of development sites, and the nature of the house-building industry in the UK.
- Through the extension of a number of mechanisms currently available to LAs, such as Community Land Trusts, Rural Exception Sites and the Social Housing Grant it should be possible to explore and encourage alternative procurement routes to deliver affordable housing in rural areas of Wales.
- Self build is a popular and successful method for delivering affordable housing across Europe and the USA. However, it is not actively encouraged within existing UK housing strategies, and only a few community based self build projects have been successfully realised.

The delivery of affordable housing is a significant concern for large areas of the UK. However this has reached acute levels in rural Wales. Studies by the JRF and WRO suggest a net shortfall in the region of 3,800 properties per year, and approximately 25,000 households were, at time of writing in 2008, registered on the 9 rural Local Authority Housing lists.

This need is the result of complex and varied economic and social conditions including;

- Lower than average income levels,
- Dramatic rises in housing prices of 176% between 1997-05 to give an average value, 12% higher than the national average,
- Increased homelessness with homeless rural households rising by 83% between 1997-98 and 2006-07.
- Net out-migration of people in the 15-29 years and a net in-migration of 50,300 people between 1991 and 2001 resulting in a skewed demographic profile with 20% of the rural population over 65 years old.
- A significant drop in social housing stock with the sale of 10,217 properties between 1996 and 2007 under the Right to Buy and Right to Acquire schemes, with just 2,865 new properties provided during the same period.

In order to address this need the WAG announced in 2007, the priority delivery of an additional 6,500 affordable homes within their One Wales strategy. However this target is still insufficient to meet the identified need, with a shortfall of 2,500 homes a year approximated by the JRF.

Data collected by Statistics for Wales state that a total of 6,707 units have been

completed during the period 1st April 2007 and 31st March 2010, successfully fulfilling the target established by the One Wales Strategy. Approximately 30%, or 2033 units, were delivered in the nine rural Authority areas. However, despite the recent fall in house prices and an increased number of affordable housing units, there remains an acute need for additional affordable housing. The current economic climate and a reduction in SHG, the primary delivery mechanism in recent years, is likely to result in increasingly challenging conditions in which to realise the additional 5,400 housing units planned for 2010 to 2012, and establish a sustainable supply of affordable housing for the long term future.

The house building industry in the UK is heavily reliant on a small number of large, commercially driven volume housebuilders. Mechanisms for delivering affordable homes are subsequently tailored to this context, with planning mechanisms such as Section 106 agreements recognised as essential to providing additional funds, land or in some cases, completed units to support public funding mechanisms. These mechanisms are generally successful in urban conditions where large scale developments and high demand significantly improve the economic profile of housing delivery. These are, however, considerably less effective in rural areas of Wales where appropriate development land is limited by;

- the restrictive nature of existing development boundaries,
- a reluctance for landowners to sell at realistic valuations,
- potential development sites providing reduced financial viability due to limited economies of scale and challenging site conditions.

Based on these findings, it can be concluded that there is significant opportunity for an innovative and alternative approach to delivering affordable housing in rural Wales. It is proposed therefore that an innovative construction system, which makes use of low value homegrown timber resources, could offer a potential solution to this application, if it;

- Is tailored to the context of small rural sites with limited construction scales, of perhaps 3-15 units, and with potentially challenging physical and climatic conditions.
- Has technologies and processes that are appropriate for adoption by local housebuilders and self builders.
- Offers and encourages an alternative procurement method for Community groups and individuals to take greater control in the delivery of affordable housing, potentially by encouraging the investment of ‘sweat equity’ in a self assembly/build or finish construction solution.
- Is appropriately designed and specified for the diverse context of rural Wales and the critical sector of affordable housing.

Chapter 3.0

Homegrown Sitka Spruce in Construction

a study of the unique properties of welsh grown sitka spruce and its application in
the modern construction industry

3.01 INTRODUCTION

Chapter 2.0 has established a clear and identifiable need for affordable housing in rural Wales. Over the past two decades, political interest in Modern Methods of Construction (MMC) has grown following a number of significant studies into the nature and performance of the construction industry. It is generally concluded that the primary mechanism for delivering better quality housing, in higher numbers and at lower cost, is to encourage a construction industry which develops and applies MMC.¹ The majority of timber based MMC systems currently used in the UK make use of imported timber or imported systems, most commonly in the form of timber framed panels. A crop of low value home grown timber, however, is available from sustainable local resources but is currently under-used by the construction industry.

In the following chapter an analysis of the primary production forest crop, Sitka Spruce, will describe the available resource, and identify potential opportunities for use as a self build solution to affordable housing.

The homegrown softwood resources of Wales, specifically Sitka Spruce, demonstrate unique physical and mechanical properties and are part of established supply chains. Any proposal to apply these resources to alternative applications will need to carefully tailor the design and development of components to the specific context and qualities of homegrown softwood. A review of the species will therefore describe the context in which the non-native species has developed into the primary production crop of the Welsh forests and, based on national statistics, establish the scale and value of the resource. It will then analyse the mechanical and physical properties of Sitka Spruce and identify the existing primary applications of homegrown Sitka Spruce in Wales.

A review of the existing timber construction industry will identify current practice and establish the scale and capacity of the existing market. With this in mind, it will then reflect upon a selection of recently published research studies into the use of home grown timber, in order to establish the primary barriers to its application through current construction practices.

Finally, an analysis of contemporary and historical construction systems will establish a source of precedent for the design, manufacture and construction of an innovative MMC. This will include an analysis of the primary barriers and threats to the development and application of an MMC system, in order to inform the development process and assist in establishing a viable construction solution.

1 National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently* (London: National Audit Office, 2005), p. 1.



CLOCKWISE FROM TOP LEFT

- Figure 3.1: Ancient oak forest, Coed Allt Wen.
- Figure 3.2: Deciduous woodlands of the Wye Valley, Symonds Yat.
- Source : Forestry Commission
- Figure 3.3: Ancient submerged forest, Y Borth.
- Figure 3.4: Glacial lake and ancient forest of Coed Allt Wen, Llyn Padarn.

3.02 THE WELSH FORESTS

The landscape of Wales, like the rest of the UK, was once covered in dense woodland extending to all but the highest of altitudes. For much of England and Wales, the climax or dominant vegetation is broadleaved deciduous forest.²

Once established, approximately 6500 years ago, the overall diversity of the native Welsh woodlands remained fairly balanced until the 17th Century, consisting of broadleaved forests dominated by Oak, with rare occurrences of pine and firs. Beginning in the 17th Century, this stable ecosystem was rapidly altered with the introduction of exotics such as Scots Pine, Norway Spruce, European Larch, Cypress and Cedar, initially for ornament on larger estates as trophies of international exploration.

Towards the end of the Middle Ages four main industries developed that placed a hugely damaging demand on the Welsh forests; charcoal, pitwood for the complex networks of the Welsh coal mines, timber for ship building, and oak bark for the tanning of leather. By the end of the 19th Century however, the decline of the major demands for Naval timber and Oak bark, and a massive influx of imported timber resulted in a wide and general decline in the economic value of woodlands, and investment all but ceased. Woodlands were no longer considered to be of economic value and many of the larger estates were split into smaller freehold farms. In 1889 the Board of Agriculture reported a total woodland area of just 4% of the total land area of Wales.

By 1914 just 8% of the wood supplies consumed in the UK were from homegrown resources. World War I therefore generated an immediate demand on homegrown resources, with imported timber quantities falling from 6.5 million tonnes in 1916 to 2.5 million tonnes in 1918. Felling in Wales to provide pitwood, timber and fuelwood was significantly higher than that required in either Scotland or England, and employment in the forest industries increased to over 2000.

Following decades of devastation and neglect, there was an increasing demand for government intervention and a general commitment to a national policy. On 19th August 1919 the Forestry Commission (FC) was established in the UK, with the objective to create ‘*reserves of standing timber sufficient to meet the essential requirements of the nation... in time of war or national emergency*’³. The demanding state program included the afforestation of 1.7 million acres of previously unplanted woodland. This began in 1921 with the planting of 300 acres across 4 sites, consisting primarily of conifers, including Douglas Fir, Corsican and Scots Pine, European and Japanese Larch, and Norway and Sitka Spruce.

Common Name	Latin Name
Alder	Alnus glutinosa
Ash	Fraxinus excelsior
Beech	Fagus sylvatica
Birch	Betula Pendula
Elm	Ulmus procera
Hazel	Corylus avellana
Hornbeam	Carpinus betula
Pendunculate Oak	Quercus robur
Scots Pine	Pinus sylvestris
Sessile oak	Quercus petraea
Sycamore	Acer pseudoplatanus
Willow	Salix alba

Table 3.1: Indigenous Welsh Timber Species

2 William Linnard, *Welsh Woods and Forests : A History* (Ceredigion: Gomer Press, 2000), p. 3.

3 Ibid., p. 190.



CLOCKWISE FROM TOP LEFT

Figure 3.5: Boat building, Cardigan, c1869

Source : Amgueddfa Cymru — National Museum Wales

Figure 3.6: Coed collier stacking cordwood, 19th Century

Source : Forestry Commission

Figure 3.7: Oak tanning bark stacked awaiting transport, 1908

Source : Amgueddfa Cymru — National Museum Wales

Figure 3.8: The steamer 'Campus', Cardiff docks, c1948

Source : Amgueddfa Cymru — National Museum Wales

Figure 3.9: Members of the Women's Timber Corps preparing small section timbers

Source : Imperial War Museum, London

Figure 3.10: Preparing pitprops, South East Coalfield, 19th Century

Source : Amgueddfa Cymru — National Museum Wales

The annual planting rate of the inter-war period increased from just over 1,100 acres per annum in 1922 to a peak of 5,000 acres per annum in 1938-40,⁴ and continued to rise following the Second World War, to a peak of 13,167 acres in 1960. Conifers made up 90% of these new plantations with new broadleaf plantations contributing just 4%.⁵ The preferred choice were the Spruce species, in particular Sitka, due to its fast growing potential in the mild, wet climate of Wales, and its ability to establish in peaty upland soils. Other species that were planted were more particular to site; Japanese or hybrid Larch, for example, were planted with areas of high mineral soils, Douglas Fir on richer soils at low altitudes and Pines, of which Corsican was the most successful, on drier sites.⁶ Between 1947 and 2007 over 600,000 hectares of Sitka Spruce were planted in the UK, helping to increase woodland cover from 67,000 to 692,000 hectares, often in single species plantations.⁷ The total area of plantations held by the FC peaked in 1982/83 at 136,849 hectares and marked a turning point between new planting and restocking. By 1995, new FC plantations had declined to zero, with all investment going into the restocking of maturing plantations.

It is within this context that a catalyst for this study emerges. Since its formation in 1989, Coed Cymru have been tasked with the key objective to heighten awareness of the native woodlands and provide help and advice on the sensitive and sustainable management of Welsh broadleaf woodland. However, following a century of strategic planting to create standing stocks of fast growing timbers, there exists a significant resource of low value, non native softwood crop. The context of mid 19th century Britain in which these strategies were determined have significantly altered, resulting in a forest industry which is dominated by relatively low value resources. New products and industries have developed to make use of Welsh timber resources however investment in the regeneration of the native Welsh woodlands remains significantly limited by the low value nature of the resource.

4 Ibid., p. 193.

5 Ibid., p. 192.

6 Ibid., p. 196.

7 Ibid., p. 2.

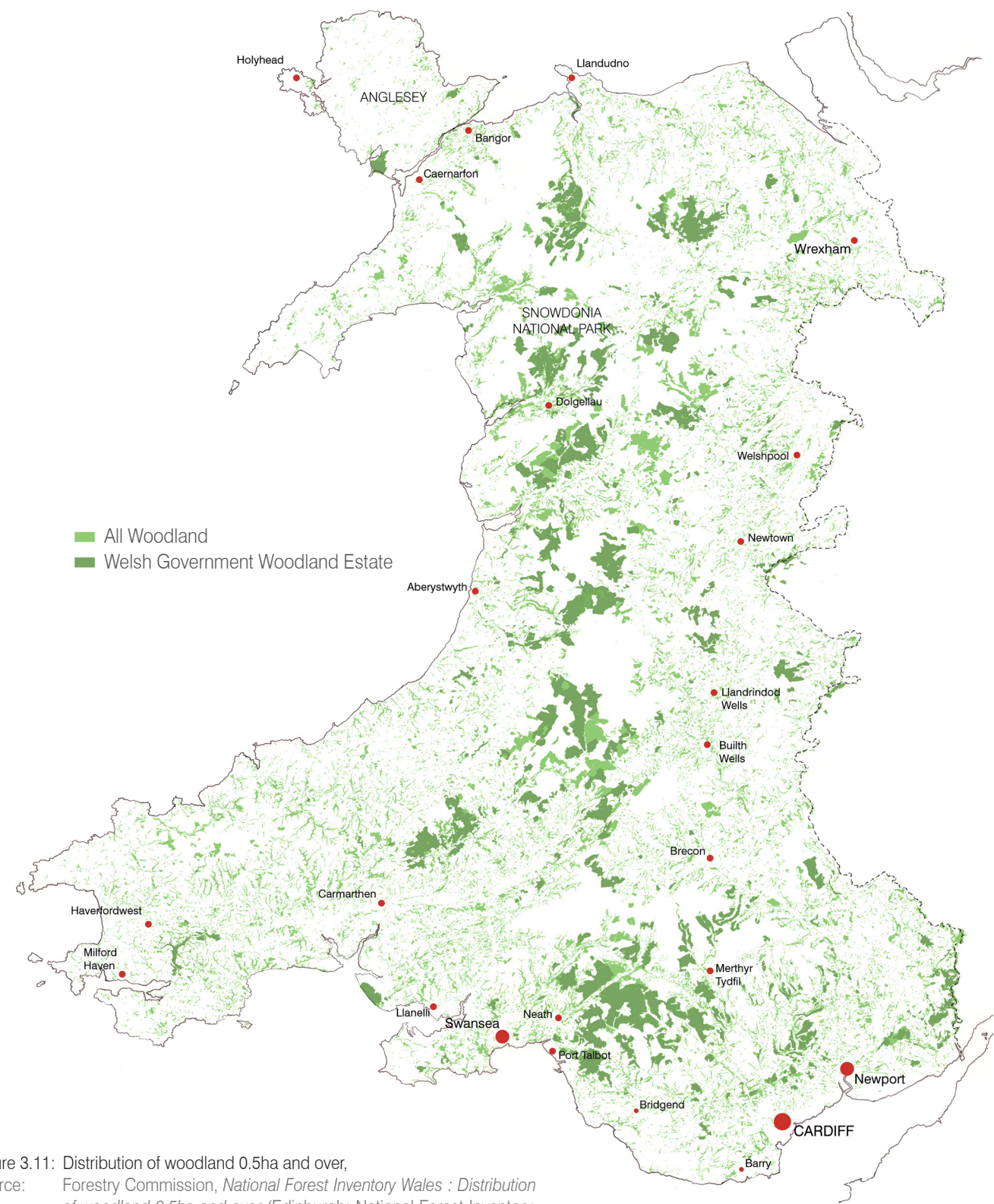


Figure 3.11: Distribution of woodland 0.5ha and over,
Source: Forestry Commission, *National Forest Inventory Wales : Distribution of woodland 0.5ha and over* (Edinburgh: National Forest Inventory, 2010), p. 1.

3.03 WOODLAND AREAS AND PLANTING

Since 1924 the FC have carried out inventories of woodland in the UK at 10-15 year intervals. The most recent of these surveys to be completed was the National Inventory of Woodlands and Trees (NIWT) carried out between 1995-99, however in 2009 the FC commenced work on the National Forest Inventory (NFI), to be completed by 2014.

The Inventory data provides a comprehensive review of the woodland industry, including data on area, ownership, certification, and species, replanting and new planting, standing timber age and many other woodland characteristics. The first data from the NFI was published in March 2011 and includes revised woodland areas, and areas of woodland loss and new planting.

The key findings of the NFI show that as of 31st March 2010;

- The area of woodland in Wales is estimated at 303,500 hectares, which is approximately 14% of the total land area of Wales.⁸
- In the period 1997-98 and 2009-10 there has been just 5,300 hectares of new woodland planting.⁹
- The preceding period of 1989-90 to 1997-98 witnessed 4,100 hectares of new woodland planting.¹⁰
- 9,100 hectares of new woodland planting provided between 1989 and 2010 was planted with the assistance of grant aid, and the remaining 200 hectares were planted by the FC.¹¹

Based on updated data from the NIWT, the FC Statistics 2010, published by the Office for National Statistics gives a more comprehensive review of the forest industry than currently available from the NFI, and provide comparative data for the rest of the UK.

The FC estimates that, as of the 31st March 2010, Wales has;

- 284,000 hectares of woodland.¹²
- 155,000 hectares of this area, approximately 55%, is identified as conifer woodland, ie a minimum of 80% of the woodland area is identified as conifer.¹³
- 129,000 hectares is identified as broadleaf woodland.¹⁴

8 Forestry Commission, *First Release : National Forest Inventory Woodland Area Statistics : Wales* (Edinburgh: National Forest Inventory, 2011), p. 1.

9 Ibid., p. 2.

10 Ibid., p. 2.

11 Ibid., p. 2.

12 Forestry Commission, *Forestry Facts & Figures 2010* (Edinburgh: Economics & Statistics, 2010), Table 1.

13 Ibid., Table 1.

14 Ibid., Table 2.

Country	Forest area (million ha)	Total land area (million ha)	Forest as % of land area	Forest area (ha) per 100 population
Europe				
United Kingdom	3	24	12	5
Finland	22	30	73	418
France	16	55	29	26
Germany	11	35	32	13
Italy	9	29	31	15
Spain	18	50	36	41
Sweden	28	41	69	306
Other EU	49	154	32	29
Total EU-27 ¹	157	419	37	32
Russian Federation	809	1 638	49	572
Total Europe	1 005	2 215	45	137
Africa	674	2 974	23	68
Asia	593	3 091	19	15
North & Central America	705	2 135	33	132
Oceania	191	849	23	548
South America	864	1 746	49	225
World	4 033	13 011	31	60

Table 3.2: Forest cover: international comparisons, 2010,
Source : Forestry Commission, *Forestry Statistics 2011* (Edinburgh: Forestry Commission, 2011), Table 9.1.

	Woodland Cover % of land area
England	9%
N Ireland	6%
Scotland	17%
Wales	14%
United Kingdom	12%

Table 3.3: Forest cover: United Kingdom, 2010,
Source : Forestry Commission, *First Release : Woodland Area, Planting and Restocking* (Edinburgh: National Forest Inventory, 2010), p. 2.

- 105,000 hectares, approximately 37%, is within the FC portfolio.¹⁵
- 179,000 hectares, 63%, is owned by non-FC organisations, including private businesses, charities, Local Authorities and personal ownership.¹⁶
- All woodland in FC ownership is certified under the Forest Stewardship Council (FSC) scheme. Some of this woodland area is also PEFC certified. Only 18,000 hectares, approximately 10%, of non-FC woodland is certified.
- 78% of the FC portfolio is identified as conifer woodland compared with just 36% of non-FC owned woodland.
- New planting in the UK has steadily declined since 1990 from nearly 30,000 hectares per year to just 5,400 hectares of new woodland planted in 2010.¹⁷
- In Wales there has been no new planting of conifers recorded in the 5 years since 2006 and only 100 hectares of new broadleaf was recorded in 2010, all by non-FC owners.¹⁸
- In contrast restocking of woodland has steadily increased in the UK since 1976, however in the last three years this has fallen to 2,100 hectares of restocking per year.¹⁹ The FC performs the majority with approximately 60% performed in conifer woodland.

The UK has a total of 2.85 million hectares of woodland, covering 12% of the total land area of the UK. Northern Ireland has the lowest proportion of woodland area, with just 6% of its land area covered in woodland. Table 3.3 shows woodland coverage data for the UK.²⁰ These percentages are particularly low when compared internationally, particularly with other EU nations. See Table 3.2. Nations such as Germany, Italy and Spain all maintain areas of over 30% woodland cover, with woodland in some of the Baltic nations reaching over 70% of land area.²¹

3.03.1 WOODLAND TREE SPECIES

The NFI has yet to provide revised data for the species mix for woodland in Wales and the UK, however the NIWT provides data for the species mix contained within the Welsh woodlands as of 31st March 1997.²²

15 Ibid., Table 2.
16 Forestry Commission, *Forestry Statistics 2011* (Edinburgh: Forestry Commission, 2011) Table 1.3.
17 Ibid., Table 3.
18 Ibid., Table 3.
19 Ibid., Table 4.
20 Forestry Commission, *First Release : Woodland Area, Planting and Restocking* (Edinburgh: National Forest Inventory, 2010) p. 2.
21 Forestry Commission, *Forestry Facts & Figures 2010*, Table 14.
22 Forestry Commission, *National Inventory of Woodland and Trees: Wales* (Edinburgh: Forestry Commission, 2002) p. 18.

Year	England		Wales		Scotland		Northern Ireland		UK		Total
	Non FC/FS	FC/FS	Non FC/FS	FC/FS	Non FC/FS	FC/FS	Non FC/FS	FC/FS	Non FC/FS	FC/FS	Non FC/FS + FC/FS
	thousand green tonnes										
2000	503	1 156	322	752	1 718	2 616	29	326	2 572	4 850	7 422
2001	544	1 075	375	779	1 942	2 354	29	396	2 890	4 604	7 494
2002	383	1 103	346	894	2 213	2 268	29	385	2 971	4 650	7 621
2003	522	1 107	320	880	2 620	2 405	29	424	3 491	4 816	8 307
2004	498	1 204	323	783	2 767	2 527	30	380	3 618	4 894	8 512
2005	595	1 165	296	673	2 963	2 388	40	353	3 894	4 579	8 473
2006	627	1 152	348	612	2 920	2 454	21	364	3 916	4 582	8 498
2007	656	1 211	409	584	3 275	2 496	29	383	4 369	4 674	9 043
2008	672	1 100	343	556	2 976	2 362	25	398	4 016	4 416	8 432
2009	564	1 213	332	717	2 433	2 773	24	423	3 353	5 126	8 479

Table 3.4: Softwood removals by country between 1999 and 2008 from FC/FS and non FC/FS woodlands,
Source : Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 2.3 - 2.4.

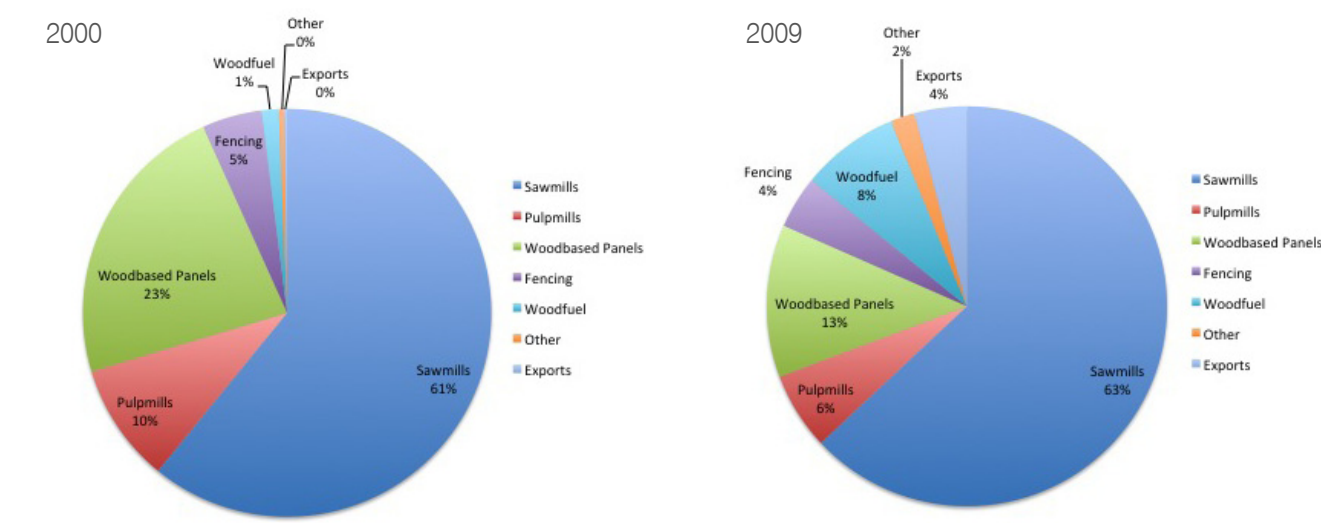


Chart 3.1: Deliveries of UK grown Softwood, 2000 and 2009
Source : Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 2.15.

- Sitka Spruce covers a total area of 81,316 hectares.
- This accounts for 56% of all conifer cover in Wales, and 33% of all woodland cover.
- The second principal conifer species is Japanese and hybrid Larch, accounting for 15% of conifer cover and 9% of woodland cover.
- Norway Spruce covers an additional 11,051 hectares taking the total Spruce cover to 63.5% of all conifer woodland.
- Oak is the principal broadleaf species, accounting for 37% of all broadleaf cover and 15% of all woodland cover.
- Ash at 17% is the second principal broadleaf species, with Birch, Beech and Sycamore all achieving a cover of over 5% each.

The NIWT provides data to suggest a categorization of quality, defining Category 1 as capable of producing wood of a size and quality suitable for sawlogs, and Category 2 as lower quality wood.²³ The majority of woodland owned by the FC is conifer woodland, approximately 87% or 93,067 hectares. Of this woodland, over 50,000 hectares is identified as Category 1 Sitka Spruce, with 5,000 hectares as Category 2 Sitka Spruce.²⁴ Non-FC woodland provides a further 25,993 hectares of Sitka Spruce with over 90% assessed as Category 1 wood. In total 73,738 hectares, approximately 29.5% of all woodland in Wales, is considered as Category 1 Sitka Spruce, capable of producing wood of a size and quality suitable for sawlogs.²⁵

The NIWT also provides information regarding the age of standing stocks. This information is particularly useful in forecasting the likely quantity and spread of mature timber stocks. The majority, approximately 89% of conifer woodland standing in Wales, was planted between 1950 and 1997. 28,655 hectares, approximately 38% of the standing stocks of Category 1 Spruce, were planted between 1950 and 1970.²⁶ With a typical rotation period of between 35 and 45 years, it is the maturing of these stocks that has enabled a large increase in softwood production over the last decade.

23 Ibid., p. 55.
24 Ibid., p. 20.
25 Ibid., p. 20.
26 Ibid., p. 22.



Figure 3.12: Removing coniferous stands
Source : Forestry Commission

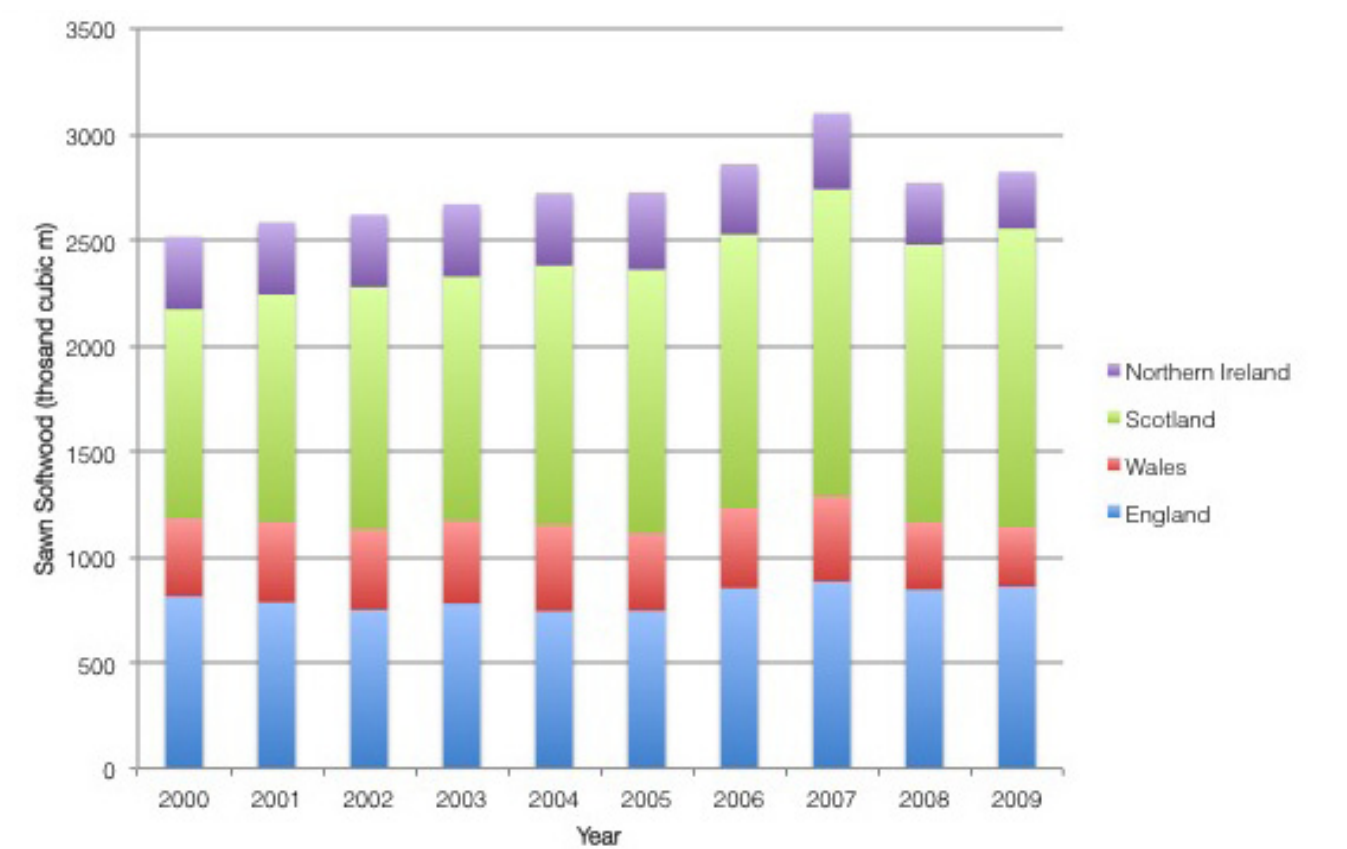


Chart 3.2: Sawn softwood production by country 2000 - 2009.
Source : Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 2.15.



Figure 3.13: Softwood processing, Deffer Wood
Source : Forestry Commission
Figure 3.14: Air drying Hardwood stacks, Wentwood Timber Store
Figure 3.15: Sorting chipped timber, Howie Forest
Source : Forestry Commission

3.04 SOFTWOOD PRODUCTION

The UK produced a total of 8.5 million green tonnes of softwood and 350 thousand green tonnes of hardwood in 2009.²⁷ Approximately 60%, of the softwood produced was sourced from FC woodlands, however only 16% of hardwood produced is sourced from the FC. Wales contributed just over 1 million green tonnes of the UK's softwood with a higher than average 70% sourced from FC woodlands.²⁸ Scotland is the largest producer of softwood contributing 61% of the total UK production in 2009.

Of the 8.2 million green tonnes of softwood delivered in 2009, 63%, or just over 5 million tonnes were delivered to sawmills for processing.²⁹ The remaining quantity were delivered to;

- Wood based panel manufacturers - 12%
- Wood fuel - 8%
- Pulp and Sawmills - 6%
- Fencing - 4%
- Exported to international markets - 4%

In contrast the majority of hardwood harvested from UK woodlands, approximately 75%, was delivered directly as wood fuel, with just 13% or 73 thousand green tonnes being delivered for processing by sawmills.³⁰

196 sawmills are registered in the UK with over two-thirds solely processing softwood. In 2009;³¹

- 5.3 million green tonnes of green softwood, including 158 thousand tonnes of imported timber, was converted by UK sawmills.
- To produce 2.8 million m³ of sawn softwood, of which approximately 178 thousand m³ was exported to international markets.

It is estimated that 76% of sawnwood produced in the UK, including hardwoods, is FSC certified.

Chart 3.2 displays the production quantities of sawn softwood by UK country. In 2009, sawmills in Wales;

- consumed just over 558 thousand tonnes, or 11% of the total UK consumption of green softwood.³²
- to produce 282 thousand m³ of sawn softwood. This demonstrates a

27 Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 2.1.
28 Ibid., Table 2.3 - 2.4.
29 Ibid., Table 2.6.
30 Ibid., Table 2.7.
31 Ibid., Table 2.8.
32 Ibid., Table 2.13.

significant decline in production since 2007, dropping from a production quantity of 405 thousand m³.³³

In Wales 7 of the 18 registered sawmills are classified as ‘large’, producing more than 10 thousand m³ of sawnwood per year.³⁴ These 7 sawmills consumed approximately 533 thousand green tonnes of softwood in 2009, of which 75% is sourced from Welsh woodlands.³⁵ This produced 268 thousand m³ of sawnwood, to supply the following primary markets;³⁶

- Construction 19%
- Fencing 28%
- Packaging 47%
- Others 6%

In addition to sawn softwood, the 7 large sawmills also supplied 295 thousand tonnes of material to other industries, with 89% going to wood processing industries, primarily in the form of wood chips but also as bark and sawdust.³⁷

FC statistics present a forecast of softwood availability between 2006 and 2026. The forecasts suggest that softwood production will continue to increase to an annual average of 11.5-12 million green tonnes. In Wales the forecast suggests a stable annual production at approximately 1.2 million tonnes.³⁸ It is forecasted that during this period, timber will become more evenly sourced from non FC and FC woodlands.

FC data does not provide a breakdown of species mix following harvesting, it is estimated however that Sitka Spruce accounts for as much as 70% of softwood production in Wales and 60% of the total softwood production in the UK. This high proportion of production can be attributed to a number of factors, including the increased productivity of spruce plantations, and the dominance of Sitka Spruce in FC plantations.

Once softwood has entered the primary processing industry there is little capacity to maintain an inventory of species type and mix. Due to the high proportion of Sitka Spruce in homegrown softwood production, it can be assumed for the purpose of this study that the performance characteristics of Sitka Spruce can be considered to generally define the characteristics of homegrown softwood.

33 Ibid., Table 2.15.
34 Ibid., Table 2.16.
35 Ibid., Table 2.17.
36 Ibid., Table 2.18.
37 Ibid., Table 2.19.
38 Ibid., Table 2.5.

Thickness (mm)	Width (mm)											
	75	100	115	125	138	150	175	200	225	250	275	300
16	✓	✓		✓		✓						
19	✓	✓		✓		✓						
22	✓	✓✓		✓✓		✓✓	✓✓	✓✓	✓✓			
25	✓✓	✓✓		✓✓		✓✓	✓✓	✓✓	✓✓	✓	✓	✓
32		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
38	✓✓	✓✓	✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓	✓	✓
47	✓✓	✓✓		✓✓		✓✓	✓✓	✓✓	✓✓	✓✓		✓✓
50	✓	✓		✓		✓	✓	✓	✓	✓		✓
63		✓✓		✓✓		✓✓	✓✓	✓✓	✓✓			
75		✓✓		✓✓		✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
100		✓✓				✓✓		✓✓	✓✓	✓✓	✓	✓✓
150						✓✓		✓✓				✓✓
250										✓✓		
300												✓✓
✓ Customary sizes of sawn softwood in the UK, included in BS 1313-1: 1997. ✓ Customary sizes of structural sawn softwood in the UK, included in BS EN 336: 2003. Note: All sizes may not be available, and may not be available in all species and grades.												

Table 3.5: Sizes of Softwood Sawn Timber
Source : TRADA, *WoodInformation Sheet 37 : Softwood Sizes* (High Wycombe: TRADA, 2005), p. 2.

3.04.1 STANDARD TIMBER DIMENSIONS.

Sawn softwood produced by Welsh sawmills can be considered in two categories, see Figure 3.16;

- Structural timber
Taken from the centre of the sawlog, giving larger section timber of a higher quality and strength.
- Falling boards
Taken from the remaining timber to the exterior of the log, sometimes including a proportion of bark to give a waney edge board.

Figure 3.16: Cross section of a tree trunk showing imposed cutting pattern.

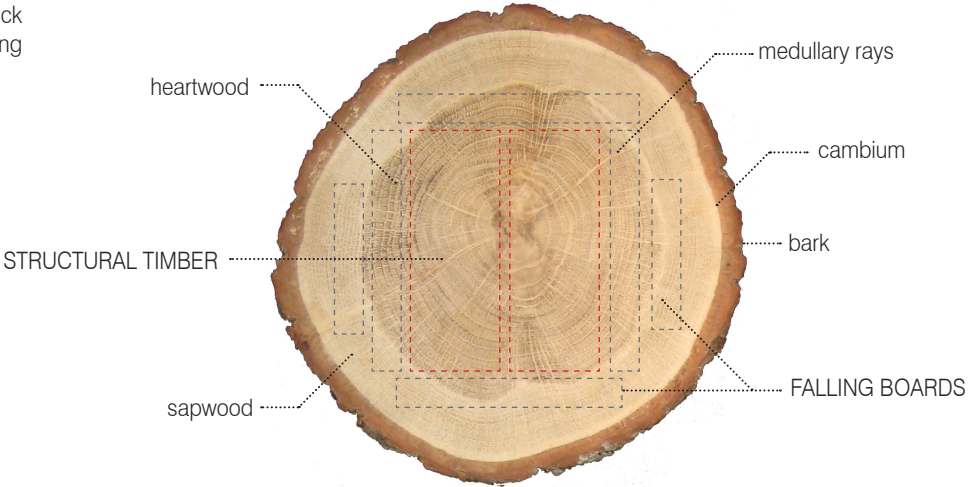


Table 3.5 published in Trada's Wood Information Sheet 37 combines the full range of target sizes for structural timber identified in BS EN 336. 2003 with customary sawn timber sizes as identified in BS 1313-1: 1997.

This full range of timber sizes for structural timber and sawn falling boards are rarely all available from Welsh sawmills. In order to ensure a stable and efficient production of material supported by sustainable marketing and supply strategies, sawmills in Wales have consciously limited the range of dimensions commonly available. Subsequently structural timber is typically available in thicknesses of 47 or 75mm with widths ranging from 75mm to 250mm. Despite demand for smaller dimension structural material, structural sections such as 38mm thicknesses are uncommon in Wales. Table 3.6 shows the most common structural sections available from Welsh Sawmills, including the major sawmills of BSW and Pontrilas Timber.

Table 3.6: Common homegrown structural softwood timber sections
Source : John Moore, *Wood properties and uses of Sitka spruce in Britain* (Edinburgh: Forestry Commission, 2011), p. 29.

width mm	50 (47)	75 (72)	100 (97)	125 (120)	150 (145)	175 (170)	200 (195)	225 (220)	250 (245)
47 (44)	✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓
75 (72)	✓	✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓

Note: Values in parenthesis are the dimensions of timber following machining on all four sides.

- ✓ - less common sizes produced by fewer mills or produced less often
- ✓ ✓ - common sizes routinely produced by most sawmills

width mm	75	100	125	150	200
16	√√	√√	√√	√	√
19	√√	√√	√	√	√
22	√√	√√	√√	√√	√

√ - less common sizes produced by fewer mills or produced less often
√√ - common sizes routinely produced by most sawmills

Table 3.7: Common homegrown small section softwood timber
Source : John Moore, *Wood properties and uses of Sitka spruce in Britain* (Edinburgh: Forestry Commission, 2011), p. 30.

Structural timbers are typically available in standard lengths of 2.4, 3.0, 3.6, 4.2 and 4.8m, with over 60% cut to 4.8m by Pontrilas Timber, however longer lengths of 5.4 and 6.0m are sometimes available by request. Odd lengths of 2.7, 3.3, 3.9, 4.5 and 5.1m are available from a limited number of suppliers.³⁹

Falling boards are typically available in three thicknesses, 16, 19 and 22mm although an additional thickness of 32mm is sometimes available. The widths of boards are typically in increments of 25mm in a range of 75mm to 200mm. As with structural timbers, falling boards are available in lengths of 1.8, 2.4, 3.0, 3.6, 4.2 and 4.8m with oversize lengths of 5.4m and 6.0m available by request. In discussion with Pontrilas Timber, attention was brought to the common sections 22x75mm and 22x125mm, which are often the result of efficient cutting patterns but are typically difficult to sell with limited demand. Consequently 125mm sections are often split into two 63mm sections for use in pallet manufacture.

A survey performed by BRE identified stock levels of 10-12 days typically maintained by BSW at their Newbridge-on-Wye site, a figure reinforced through discussion with Pontrilas Timber.⁴⁰

3.04.2 IMPORTED TIMBER

The UK is one of Europe's largest importers of wood products, with approximately 85% of the domestic demand for wood products met with imports.⁴¹ In 2009, the UK imported;⁴²

- 4.86 million m³ of coniferous sawnwood
- 381 thousand m³ of non coniferous sawnwood
- 2.5 million m³ of wood based panel products
- 7 million tonnes of paper and paperboard

39 John Moore, *Wood properties and uses of Sitka Spruce in Britain* (Edinburgh: Forestry Commission, 2011), p. 29.
40 Dennis Jones, *Bridging the Gap Phase 1 : Scoping Study : Welsh timber resources and their potential within the construction industry* (Margam: BRE Wales, 2007), p. 12.
41 Forestry Commission, *Forestry Statistics 2010*, Table 3.1.
42 Ibid., Table 3.2.

The total value of imported wood products in 2009 was £5.8 billion.⁴³ The majority, 70%, is in the form of pulp and paper, 16% as sawnwood, 12% woodbased panels and 2% other wood.

The value of softwood imports has steadily increased since the 1960s and figures from the past ten years show sawnwood quantities of between 8 and 9 million m³, however this has dropped dramatically in recent years with apparent consumption falling by 22% between 2007 and 2009.⁴⁴ Imported sawnwood however still accounts for 64% of the softwood consumed within the UK market. Table 3.8 shows the type and value of UK timber imports over the past decade.

Approximately 91%, of imported sawn softwood originates from the EU with Sweden remaining the major contributor accounting for 53% of the total imported.⁴⁵ The Baltic states, particularly Latvia, emerged as significant contributors in the 1990s, and has steadily provided increased quantities of sawnwood to the UK. It is generally believed that this trend will continue and become a significant influence on the UK timber market with low value supplies increasing from Russia and other former USSR states.⁴⁶

Year	Wood (thousand m3)			Wood (£ million)		
	Sawnwood	Other Wood	Wood based panels	Sawnwood	Other wood	Wood based Panels
2000	7 852	735	3 307	1 105	67	683
2001	7 801	887	3 598	1 057	73	731
2002	8 432	1 020	3 782	1 107	79	781
2003	8 933	1 045	3 492	1 225	98	767
2004	8 583	1 048	4 114	1 190	95	961
2005	8 341	1 325	3 939	1 120	114	918
2006	7 963	1 133	3 959	1 144	112	926
2007	8 469	1 621	3 858	1 516	128	914
2008	5 886	1 921	3 389	1 085	158	873
2009	5 240	946	2 500	953	101	677

Table 3.8: Volume and value of wood imports by product 2000 - 2009
Source : Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 3.4 and 3.6.

Source	Sawn softwood	Sawn hardwood	Plywood	Particle board	Fibreboard	Wood Pulp	Paper and Paperboard
Sweden	53	1	1	0	1	8	16
Finland	13	0	12	0	3	30	17
Germany	6	8	1	18	22	1	19
France	0	5	1	19	1	0	10
Belgium	1	1	2	10	7	0	2
Spain	0	1	1	3	15	4	2
Ireland	5	2	1	39	35	0	1
Latvia	10	3	1	1	2	0	0
Other EU-27	3	15	2	10	11	11	16
Total EU-27	91	37	20	100	96	54	82
China	0	3	23	0	0	0	3
USA	0	26	0	0	0	9	3
Brazil	0	0	25	0	0	20	2
Malaysia	0	6	14	0	0	0	0
Russia	5	1	5	0	0	0	1
Cameroon	0	9	0	0	0	0	0
Other non-EU	3	18	11	0	2	16	10
Total Non-EU	9	63	80	0	4	46	18

Table 3.9: Country of origin of wood imports to the UK, 2009.
Source : Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010), Table 3.8.

43 Ibid., Table 3.6.
44 Ibid., Table 3.4.
45 Ibid., Table 3.8.
46 Dennis Jones, *Bridging the Gap Phase 1 : Scoping Study : Welsh timber resources and their potential within the construction industry*, p. 7.

3.05 HOMEGROWN SITKA SPRUCE

Sitka Spruce has become the predominant species in Welsh plantations because of its liking for the mild, wet climate and its ability to establish in peaty upland soils. In its native range, along the Pacific Northwest coast of North America, Sitka Spruce grows slowly, producing a pale coloured timber with exceptional strength to weight ratio, leading to its use in the manufacture of aircraft frames. Welsh spruce however grows much faster producing timber of lower density with heavier branching and larger knots.

As identified in Section 3.04, Sitka Spruce accounts for up to 70% of softwood produced in Wales. Sitka Spruce is generally considered to be the most troublesome of homegrown softwoods to incorporate into construction due to its unique mechanical and physical properties. Therefore this study has adopted the approach that a construction solution must be tailored specifically to the properties of Sitka Spruce with the assumption that most homegrown softwood has capacity to perform at least as well as Sitka Spruce.

The following section will describe the growth of Sitka Spruce and provide a brief description of the unique properties of homegrown Sitka Spruce.

3.05.1 GROWING SITKA SPRUCE

Sitka Spruce as introduced from the Pacific coastline of North America is adapted to high atmospheric moisture particularly suited to a maritime climate. The FC therefore advise that Sitka should be planted in sites with more than 1000mm of annual rainfall, unless soils are typically moist.⁴⁷ Sitka Spruce grows very well in deep, moist and well-drained soils, specifically those with a poor to medium nutrient status. It is largely unique in having a tolerance to drained peats and gleys as frequently found in upland Wales.⁴⁸ This has resulted in Sitka Spruce becoming the species of choice for commercial plantations in upland locations in the North and West of Britain. The species is considered to be hardy and tolerant of exposure and cold, however it is prone to late Spring frosts and pollution.⁴⁹ Natural regeneration is common among Sitka Spruce stands as seeds dropped naturally grow extremely well.⁵⁰

Early plantations of Sitka Spruce were set at close spacings of between 1.0 and 1.5m, this however increased to between 2.4 and 2.7m by 1980.⁵¹ Increased initial spacings result in an increased branch size, a deeper living crown, greater



Figure 3.17: Distribution of native Sitka Spruce along the Pacific Northwest coast of North America

Source : John Moore, *Wood properties and uses of Sitka Spruce in Britain* (Edinburgh: Forestry Commission, 2011), p. 29.

47 Forestry Commission, *Tree Species and Provenance : Sitka Spruce* (Edinburgh: Forestry Commission) <<http://www.forestry.gov.uk/fr/INFD-8CYJLU>> [accessed 18 June 2012]
48 Ibid.
49 Ibid.
50 Forestry Commission, *Sitka spruce - picea sitchensis* (Edinburgh: Forestry Commission) <<http://www.forestry.gov.uk/forestry/INFD-5NLEJ6>> [accessed 18 June 2012]
51 John Moore, *Wood properties and uses of Sitka Spruce in Britain*, p. 23.



Figure 3.18: Dense crown of Sitka Spruce branches.

Source : <<http://webpub.allegheny.edu/dept/envisci/ESInfo/comps/phinnen/website%20%28Background%29.html>>



Figure 3.19: Spruce plantation showing planting spacings of approximately 2m.

Source : <<http://suitablydespairing.blogspot.co.uk/2010/10/government-cant-see-wood-for-trees.html>>

stem taper and typically increased growth rates. It therefore typically correlates with a higher yield of timber but a lower yield of structural quality timber. Therefore Brazier and Mobbs (1993) recommend a maximum spacing of 2m x 2m to give a density of 2,500 trees per hectare.⁵²

Relatively close spacings such as these result in a very dense canopy, which limits the amount of sunlight reaching the woodland floor. It is common therefore for Sitka plantations to be dense monocultures with very limited growth of plants on the woodland floor. Historically, the resultant density and close spacing of Sitka Spruce plantations have met considerable opposition from the general public due to the monotony, limited light levels and barren woodland floors. However the maturing of plantations and the greater level of continuous cover forestry has encouraged the development of forest based recreation and activities. The predominantly softwood forests of Coed Llandegla, Coed Trallwm, Coed y Brenin, Afan, Cwmcarn and Nant yr Arian all have purpose built mountain biking centres which are considered some of the leading outdoor pursuit facilities in the UK.

APPEARANCE

Sitka Spruce takes on a conical shape with upper branches ascending to form a pointed crown and lower branches typically drooping and heavier. Branches are arranged around the straight main stem at regular intervals in a ring of shoots. Sitka Spruce is a relatively shade tolerant species and therefore it typically maintains a deeper crown of living branches than less tolerant species such as Douglas Fir, and species of Pine and Larch.⁵³

The bark of the Sitka Spruce is thin and smooth when young however, as it matures, it develops scaly, flaky plates and curved fissures with a greyish brown and purplish colour.

52 John Moore, *Wood properties and uses of Sitka Spruce in Britain*, p. 23.
53 Ibid., p. 9.



Figure 3.20: Natural regeneration of Sitka Spruce in Coed Glasfryn

The leaves of Sitka Spruce are sharp pointed, hard and flattened needles that grow individually on short stalks, which remain as pegs when the needles fall. Needles typically grow to between 15 and 25mm and have a green colour to the upper face and a bluish-white colour to the underside. Male and female trees develop small red flowers at the tips of branches in the upper sections of the tree. Once female trees reach about 20 years old, these flowers develop into pale brown cones of about 5-10 cm long which hang down from the branches, with hard, crinkled scales protecting the seeds contained inside.

ROTATION LENGTH + YIELD CLASS

Sitka spruce has a mean yield class of 14 cubic metres per hectare per year in Great Britain, however many sites are far more productive, achieving yield classes of 16-20m³ha⁻¹yr⁻¹.⁵⁴ In comparison, Oak can have a yield class as low as 4m³ha⁻¹yr⁻¹, whilst Douglas Fir is relatively similar with a yield class range of 10-24m³ha⁻¹yr⁻¹.⁵⁵

The rotation length for commercial plantations of Sitka Spruce in Great Britain is typically between 35 and 45 years. Therefore at a yield class of 14, a Sitka Spruce stand would reach a mean height of 16 - 23m.⁵⁶ Tree diameter is less predictable however Sitka is typically harvested when a diameter of between 25 and 40cm is reached at breast height.⁵⁷

The rotation length for commercial plantations of Sitka Spruce has generally been reducing due to improvements to tree stocks enabling woodland owners to realise financial returns quicker. However the shortening of rotation lengths can have a negative affect on the mechanical properties of harvested timber.⁵⁸ As rotation lengths increase, the proportion of juvenile timber present in the harvested crop decreases and subsequently produces dramatically higher strength timber. At 35 years old, a plantation of unthinned Spruce typically contains 50% of its volume as juvenile timber. By 45 years old this proportion has decreased to 35%.⁵⁹ It is possible therefore, through the extension of rotation lengths that a higher proportion of yield could be suitable for C24 classification.⁶⁰

54 Ibid., p. 2.
55 A.L. Tyler, D.C. MacMillan and J. Dutch, *Models to Predict the General Yield Class of Douglas Fir, Japanese Larch, and Scots Pine on Better Quality Land in Scotland* (Edinburgh: Institute of Chartered Foresters,1996), p. 18.
56 Ibid., p. 3.
57 Ibid., p. 3.
58 Ibid., p. 24.
59 Ibid., p. 11.
60 John Moore and Others, *Properties of UK-Grown Sitka Spruce: Extent and Sources of Variation*, (Edinburgh: Napier University, 2008), p. 7.

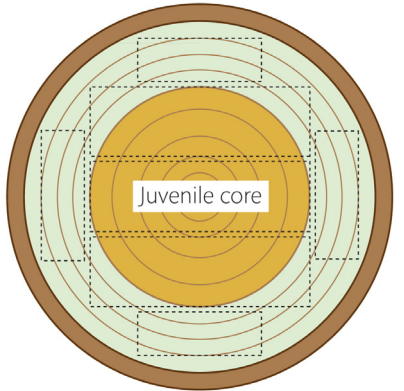


Figure 3.21: The needles and cones of Sitka Spruce.
Source : <http://www.alaska-in-pictures.com/picture-of-sitka-spruce-cones-8873-pictures.htm>
Figure 3.22: Typical cutting pattern used for Sitka Spruce logs in Great Britain.
Source : John Moore, *Wood properties and uses of Sitka Spruce in Britain* (Edinburgh: Forestry Commission, 2011), p. 28.

Durability Class	Description
1	Very Durable
2	Durable
3	Moderately Durable
4	Slightly Durable
5	Not Durable

Table 3.10: Classes of natural durability of wood to fungal attack.
Source : British Standards, *BS EN 350-1:1994 Durability of wood and wood-based products*. (London: British Standards Institution, 1994)

3.05.2 PHYSICAL PROPERTIES OF SITKA SPRUCE

COLOUR AND APPEARANCE

Sitka Spruce wood ranges from creamy white/ yellow in colour to pale pink or pinkish brown in the central core.⁶¹ It is generally referred to as whitewood in the trade, grouped with other European Spruce species such as Norway Spruce, however it tends to be slightly darker than other Spruce species. When dry there is very little difference in colour between heartwood and sapwood, but heartwood is typically slightly pinker in colour. The grain is typically straight with a medium texture dependent on the rate of growth.

DENSITY

The density of softwood is largely determined by the quantity of earlywood produced during each growth period. In Sitka Spruce earlywood has an average density of 310kg/m³, and latewood an average density of 530kg/m³.⁶² On highly productive sites, such as those found in Wales, Sitka Spruce grows more quickly producing more earlywood resulting in a lower density timber.

The Centre for Timber Engineering at Napier University gives the density of sawn Sitka Spruce at 12% moisture content as 390 ± 40kg/m³.⁶³ BS EN 5268-2: Annex A gives the approximate mean density at a moisture content of 20% for British Spruce, *Picea Sitchensis* at 400kg/m³.⁶⁴

KNOTS

Sawn Sitka Spruce commonly displays a large quantity of small knots evenly distributed along the tree stem, many of which are dead knots, ie knots formed by growth around a dead branch. A comparative study of homegrown and imported timber samples performed by BRE found that the proportion of knot area in one face of homegrown timber samples was 60% greater than found in imported timber. The study also found that UK softwood contained 38% more knots with a diameter over 10mm and the average knot size was 12% larger than found in imported timber.⁶⁵

NATURAL DURABILITY

Sitka Spruce heartwood is classified as Durability Class 4, slightly durable, and sapwood is classified as Durability Class 5, not durable, see Table 3.10.⁶⁶

61 John Moore, *Wood properties and uses of Sitka Spruce in Britain*, p. 11.
62 Ibid., p. 13.
63 Ibid., p. 13.
64 British Standards, *BS 5268-2:1996 : Structural use of timber - Part 2 : Code of practice for permissible stress design, materials and workmanship* (London: British Standards Institution, 1996), p. 156.
65 Cedric Wilkins, *Comparison of home grown and imported softwood for Timber Frame market – Final Report* (Watford: Building Research Establishment, 2004), p. 15.
66 John Moore, *Wood properties and uses of Sitka Spruce in Britain*, p. 15.

Mechanical Property	Reference	Specimen type ¹	Value
Bending strength (N mm ⁻²)	Brazier <i>et al.</i> (1976)	SC	61
	Lavers (1983)	SC	67
	McLean (2008)	SC	59
	Moore <i>et al.</i> (2009a)	FS	36
	Moore <i>et al.</i> (2009b)	FS	31
Modulus of elasticity (N mm ⁻²)	Brazier <i>et al.</i> (1976)	SC	8400
	Lavers (1983)	SC	8100
	McLean (2008)	SC	6800
	Moore <i>et al.</i> (2009a)	FS	7900
	Moore <i>et al.</i> (2009b)	FS	7830
Work to maximum load (kJ m ⁻³)	Lavers (1983)	SC	79
Work to total fracture (kJ m ⁻³)	Lavers (1983)	SC	125
Impact bending (mm)	Lavers (1983)	SC	510
Compression strength parallel to grain (N mm ⁻²)	Brazier <i>et al.</i> (1976)	SC	31.3
	Lavers (1983)	SC	36.1
Compression strength perpendicular to grain (N mm ⁻²)	CTE (unpublished data)	FS	2.8
Side hardness (N)	Lavers (1983)	SC	2400
Shear strength parallel to grain (N mm ⁻²)	Lavers (1983)	SC	8.7
	Khokhar <i>et al.</i> (2010) ²	FS	7.2
Modulus of rigidity (N mm ⁻²)	Khokhar <i>et al.</i> (2010) ²	FS	520
Resistance to splitting in radial plane (N mm ⁻¹)	Lavers (1983)	SC	7.7
Resistance to splitting in tangential plane (N mm ⁻¹)	Lavers (1983)	SC	10.0

¹ SC = small clear specimen, FS = full-sized specimen containing defects.

² Shear properties measured using a torsion testing machine.

Table 3.11: Mechanical properties of wood from UK - grown Sitka spruce. Values presented are for wood at 12% moisture content.

Source : John Moore, *Wood properties and uses of Sitka Spruce in Britain*, (Edinburgh: Napier University, 2011), p. 19.

S t a n d a r d Name	Grade	Bending Parallel to Grain N/mm²	Tension Parallel to Grain N/mm²	Compression		Shear Parallel to Grain N/mm²	Modulus of Elasticity	
				Parallel to Grain N/mm²	Perpendicular to Grain N/mm²		Mean N/mm²	Minimum N/mm²
British Larch	SS	7.5	4.5	7.9	2.1	0.82	10 500	7 000
	GS	5.3	3.2	6.8	1.8	0.82	9 000	6 000
British Pine	SS	6.8	4.1	7.5	2.1	0.82	10 500	7 000
	GS	4.7	2.9	6.1	1.8	0.82	9 000	6 000
British Spruce	SS	5.7	3.4	6.1	1.6	0.64	8 000	5 000
	GS	4.1	2.5	5.2	1.4	0.64	6 500	4 500
D o u g l a s Fir (British Grown)	SS	6.2	3.7	6.6	2.4	0.88	11 000	7 000
	GS	4.4	2.6	5.2	2.1	0.88	9 500	6 000

Table 3.12: Grade stresses for a selection of British grown softwoods graded in accordance with BS 4978: for service classes 1 and 2

Source : British Standards, *BS 5268-2:2002 Structural use of timber : Part 2* (London: British Standards Institution, 2002), Table 10.

In addition to low natural durability, Sitka Spruce is classified in EN350-2 as being difficult to treat with preservatives.⁶⁷ When applied to Sitka Spruce, preservatives such as pressure applied Tanalith E are not able to penetrate deep into the timber section, instead forming a thin layer of treated wood at the extents of the sections and batten ends which is susceptible to damage.

3.05.3 MECHANICAL PROPERTIES OF SITKA SPRUCE

The research report ‘*Wood properties and uses of Sitka spruce in Britain*’ provides a comprehensive study of the mechanical properties of homegrown Sitka Spruce. Data has been compiled from studies performed over the last 30 years on specimens of Sitka Spruce with a moisture content of 12%.⁶⁸ These are summarised in Table 3.11.

Table 3.12 taken from BS 5268-2:2002 Table 10 shows grade stresses for a selection of British grown softwood species including British Spruce graded in accordance with BS 4978.

3.05.4 IN SUMMARY

Sitka Spruce is a non-native conifer which has become the primary production crop in Wales due to its ability to yield high quantities of timber in challenging soil and climatic conditions. Its physical and mechanical properties are generally considered the most restrictive of the homegrown softwoods. It can be summarised that British grown Sitka Spruce;

- Has a high frequency of small knots evenly distributed along the stem.
- Has a poor natural durability and is difficult to treat with preservatives.
- Has a low density due to its high production rate on Welsh sites, resulting in relatively poor mechanical properties.
- Has the potential to yield grades up to C24, however almost all UK grown Sitka is machine graded to C16 with yields of over 90% common.⁶⁹ It is possible for higher grades to be yielded through a multiple grade test such as a C24/ C16/ Reject test set up, however this typically results in high quantities of rejected timber.⁷⁰
- Has relatively low compressive strength in both longitudinal and lateral directions to the grain and is also found to have a low value of hardness, approximately 25-50% lower than values for Douglas Fir, Scots Pine and UK Larch.⁷¹

67 Ibid., p. 16.

68 Ibid., p. 19.

69 Ibid., p. 30.

70 Ibid., p. 30.

71 Ibid., p. 20.

3.06 HOMEGROWN SITKA SPRUCE IN USE

As previously discussed sawn carcassing timber remains the largest and most valuable commodity produced from homegrown Sitka spruce. However as the industry and production quantities have increased a number of alternative applications and markets have been identified. In addition to low value products such as woodfuel and fencing, the unique properties of Sitka spruce, including its relatively low density, light colour and fibre size, has made it specifically appropriate for the manufacture of paper, panel products and pallet and packaging.

- Sawmills for processing as Sawnwood - 63%
- Wood based panel manufacturers - 12%
- Wood fuel - 8%
- Pulp and Sawmills - 6%
- Fencing - 4%
- Exported to international markets - 4% ⁷²

The identification of potential markets for Sitka spruce has remained a subject of great interest to the industry due to the increasing availability and decreasing quality of homegrown Spruce stocks. Recent studies have proposed that an increased use of structural roundwood poles for applications such as piling and transmission posts, and the production of cladding for the construction industry may offer valuable alternative markets.⁷³

72 Forestry Commission, *Forestry Statistics 2010*, Table 2.6.
73 John Moore, *Wood properties and uses of Sitka Spruce in Britain*, pp. 27-28.

3.07 TIMBER CONSTRUCTION IN THE UK

In the following section, an analysis of industry statistics will identify the scale and capacity of the existing timber frame construction industry and its market share of the house building sector. A review of best practice literature will then summarise the primary technologies and resources used by the existing industry. By establishing the scale and context of the existing industry, later sections will consider the opportunities and barriers within the industry for homegrown timber construction components.

By the early 1980s timber frame construction accounted for approximately 27% of all new housing in the UK,⁷⁴ predominantly in the form of modern platform frame with an outer leaf cladding of brick. However in 1983 the investigative current affairs series, World in Action, broadcast a damning review of the timber frame construction industry in the UK causing a catastrophic drop in favour. The programme placed hidden cameras on a number of large developer housing sites, and used the footage to expose terrible levels of workmanship and quality control. The programme identified 30 recurring defects, but specifically highlighted issues with the watertightness of dwellings and the installation of vapour control layers.⁷⁵ The investigation stated that condensation within the structure had caused incidents of rotting in 9 year old examples in Cornwall, and went on to state that owners of timber frame properties could expect similar problems in the future.

The programme also generated considerable panic with the claim that timber frame construction presented a significant fire risk over masonry construction citing as an example a domestic fire in a Barratt home constructed in the Midlands. Barratts Homes witnessed a fall in sales by more than 50% in two years, and they subsequently abandoned timber frame and off site construction methods entirely for more than 20 years.⁷⁶

The timber frame construction industry plummeted overnight, with timber new builds accounting for just 3% of housing starts in England and Wales.⁷⁷ The Scottish timber construction industry was considerably more resilient thanks to its greater dependency on local timber resources and the existence of a stronger and more robust industry prior to the documentary.⁷⁸ Following the documentary's airing the industry slowly increased its market share to reach a market share of

74 Julian Owen, *Kit and Modern Timber Frame Homes : The Complete Guide* (Marlborough: The Crowood Press, 2007), p. 16.

75 Ibid., p. 16.

76 Josephine Smit, *20 years after World in Action, Barratt goes back into prefab* (London: Building.co.uk, 2003) < <http://www.building.co.uk/news/finance/20-years-after-world-in-action-barratt-goes-back-into-prefab/1030087.article>> [accessed March 2011]

77 Julian Owen, p. 16.

78 Keith Ross, *Non-traditional housing in the UK – A brief review* (Watford: BRE, 2002), p.10.

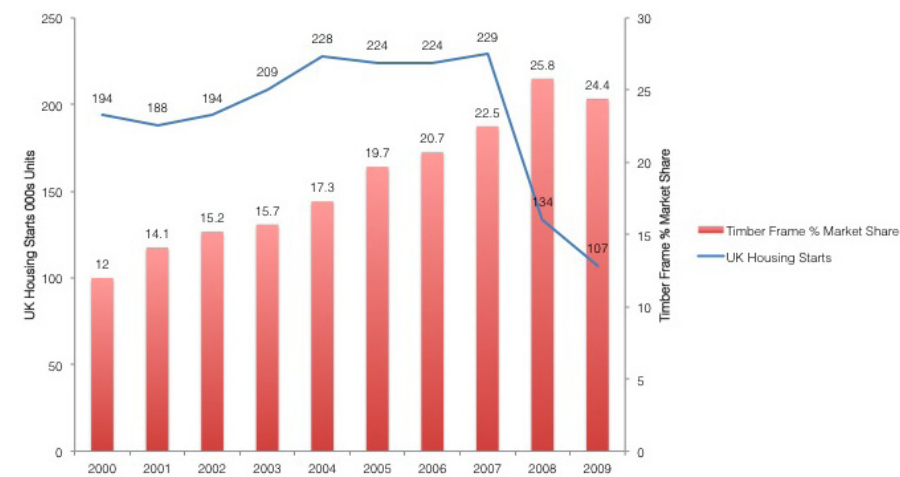


Chart 3.3: Number of Housing Starts in the UK and the Timber Frame Market Share, 2000 - 2009
Source : Timbertrends, *Market Report 2009* (Alloa: UK Timber Frame Association, 2010), p. 4.

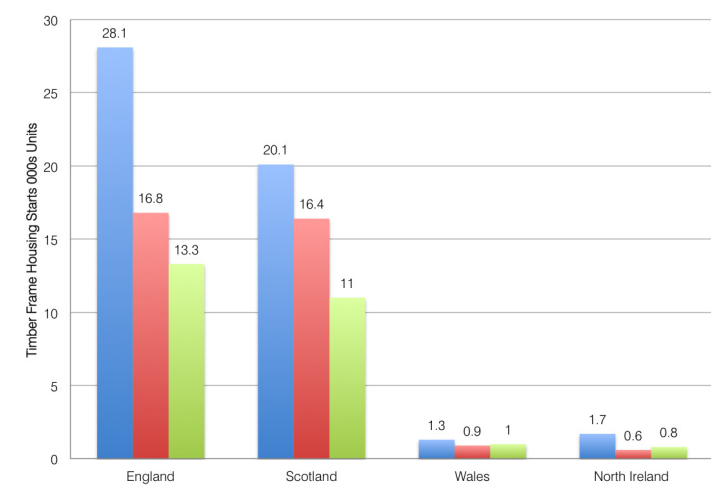


Chart 3.4: Timber Frame Housing Starts by Country, 2007 - 2009
Source : Timbertrends, *Market Report 2009* (Alloa: UK Timber Frame Association, 2010), p. 6.

8% by 1998. However investment into technical and manufacturing innovation has remained significantly limited. The last decade however has witnessed a resurgence in timber frame construction as interest in Modern Methods of Construction and sustainability has placed increased demands on a relatively stagnant and under performing construction industry.

3.07.1 MARKET SHARE OF TIMBER FRAME

The UK Timber Frame Association annually produces market share statistics for the use of timber frame solutions for the construction of all new housing based on data independently collected from their members.

The 2009 Market update shows for the first time in over a decade a decline in the proportion of new housing starts using timber frame construction. Since 1998 the share of new housing starts in the UK completed in timber frame has annually risen from 8.4% to a figure of 25.8% in 2008.⁷⁹ However 2009 figures show a slight decrease to 24.4%. This is reflective of a substantial fall across the entire industry. Housing starts in the UK rose to 229,000 units in 2007 however this has fallen by over 50% in 2008 and 2009 to approximately 134,000 and 107,000 units respectively.⁸⁰

During this period timber frame construction has suffered slightly worse than the general construction industry. 2009 figures suggested a fall of 25% of timber frame housing starts compared with a 19.2% fall in non timber frame starts.⁸¹ This can largely be contributed to the fall in timber constructions in Scotland, dropping from 74.7% to 67.5% between 2008 and 2009, accounting for over three quarters of the timber frame housing starts that have been lost.⁸² All other countries in the UK recognised growth of the market share. Wales witnessed the largest growth, rising 9.5% from 15.5% in 2008 to 21.6% in 2009,⁸³ approximately 1028 of the 4800 new housing starts in 2009. See Chart 3.4.

Government statistics show that timber frame construction has now risen to account for over 60% of all social housing starts in the United Kingdom.⁸⁴

79 Timbertrends, *Market Report 2009* (Alloa: UK Timber Frame Association, 2010), p. 4.
80 Ibid., p.4.
81 Ibid., p. 4.
82 Ibid., p. 6.
83 Ibid., p. 6.
84 The Construction Index, *Timber-frame most popular social housing building method, despite fire risks* (The Construction Index, 2010), <<http://www.theconstructionindex.co.uk/news/the-construction-index-news/Timber-frame-most-popular-social-housing-building-method-despite-fire-risks>> [accessed 20 October 2011]

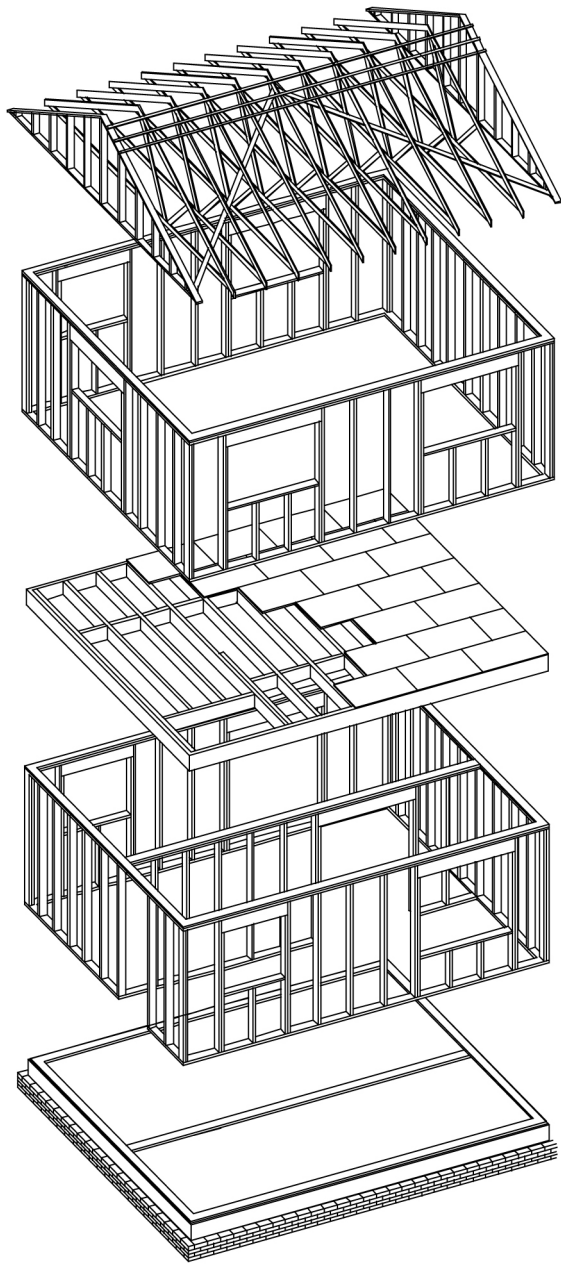
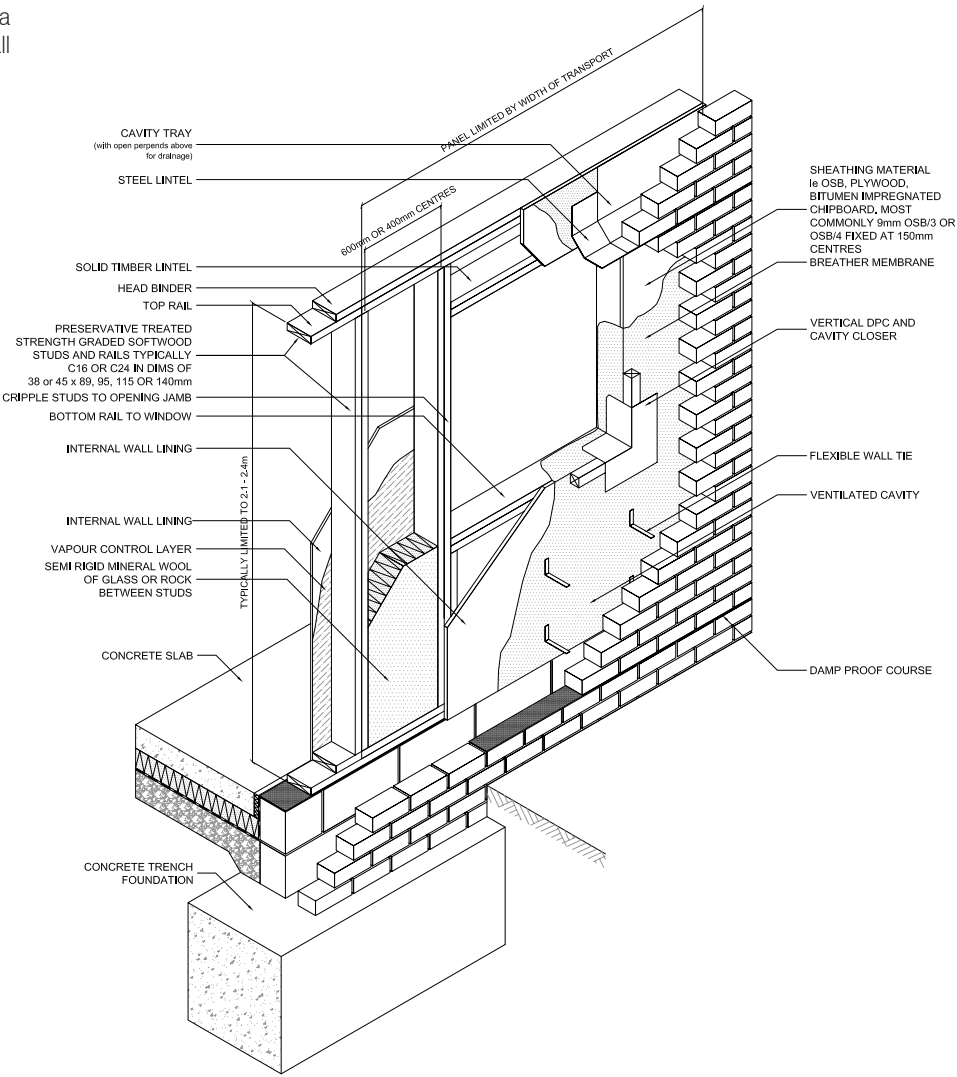


Figure 3.23: Platform frame construction with trussed rafter roof.
Source : Huel Twist and Robin Lancashire, *Timber Frame Construction*, 4th edn (High Wycombe: TRADA, 2008), p. 17.

3.07.2 MODERN TIMBER FRAME DESIGN IN THE UK

Timber frame construction is considered to be when timber is employed for all structural members in the superstructure, ie external walls, intermediate floors, internals partitions and roofs to transmit all structural loads to the foundations.⁸⁵ In the UK, platform frame construction is the most common type of timber frame construction, see figure 3.23.⁸⁶ Approximately 95% of all timber frame constructions in the UK employ factory manufactured single storey wall frames, cassette or loose floor systems and trussed rafters, with the majority utilising prefabricated 'Open' wall panels.⁸⁷

Figure 3.24: Typical arrangement of a timber platform frame wall construction



85 Huel Twist and Robin Lancashire, *Timber Frame Construction*, 4th edn (High Wycombe: TRADA, 2008), p. 17.
86 Ibid., p. 18.
87 TRADA, *Wood Information Sheet 3 : Introduction to timber framed construction* (High Wycombe: TRADA, 2006), p. 2.

3.08 HOMEGROWN SOFTWOOD IN THE CONSTRUCTION INDUSTRY

The Forestry Commission in partnership with BRE have performed a number of formal studies to consider the greater application of homegrown softwood in the construction industry. These studies include comparative studies of the respective performance qualities of homegrown and imported timber, qualitative investigations of the construction industry and continued informal communication with company leaders in both the forest and construction industries.

3.08.1 A COMPARISON OF HOME GROWN AND IMPORTED SOFTWOOD

The comparison study was performed in early 2004 by BRE on behalf of the Forestry Commission. The study compared sample batches of home grown and imported softwood to assess distortion, the quantity of compression wood, the size and frequency of knots, and in conjunction with timber frame manufacturer Stewart Milne Timber Systems, production trials and the racking resistance of home grown timber when applied to panels.⁸⁸

The study found;

- Both home grown and imported softwood showed low levels of distortion as supplied however home grown timber showed a greater tendency to distort in bow and spring when dried without restraint. This is believed to be due to the quantity of compression wood in the sample.⁸⁹
- Distortion due to twist was 20% higher in home grown timber following unrestrained conditioning.⁹⁰
- Most of the bow present in the supplied timber is caused by poor support, ie stickering, during processing, storage and transport.
- Homegrown timber displayed a much higher frequency and scale of knots with a 60% higher total knot area. 38% more of these knots are over 10mm in size making the average knot size 12% larger in home grown timber.⁹¹
- The greater frequency in knots is believed to have contributed to a better performance of homegrown timber in compression tests.⁹²
- The frequency and size of knots in homegrown timber did not result in more instances of nail fouling during production trials by Stewart Milne Timber Systems, however the tests were limited.⁹³

88 Cedric Wilkins, *Comparison of home grown and imported softwood for Timber Frame market – Final Report*, p. 1.

89 Ibid., p. 11.

90 Ibid., p. 11.

91 Ibid., p. 15.

92 Ibid., p. 19.

93 Ibid., p. 20.

- The shrinkage differential when comparing home grown and imported material for studs is minimal.⁹⁴
- No significant distortion was found in panels when conditioned from supplied moisture content to levels below those anticipated in service, suggesting that the panel construction provides a high level of restraint to the timber.⁹⁵

The study concludes that home grown timber is ‘well-suited to timber frame panel manufacture’ in terms of its general performance. However the study met resistance from research partners, Stewart Milne Timber Systems, who refused to fabricate panels for inclusion in any full scale structures using home grown timber.⁹⁶

3.08.2 ‘BRIDGING THE GAP’ RESEARCH PROJECT

In 2007, Carey Lewis and Dennis Jones of Wood Knowledge Wales undertook a survey of timber frame and roof truss manufacturers in Wales on behalf of BRE. The study hoped to assess the requirements of the industry in order to determine the medium and long term potential of Welsh softwood in construction. The study formed part of the ‘Bridging the Gap’ research project funded by the Forestry Commission.

THE SURVEY

The survey hoped to encompass the whole timber construction product industry in Wales. 33 timber frame and roof truss manufacturers were identified and contacted. The survey was conducted by telephone and included five questions covering the percentage of timber quantity by grade, the source of material and the attitude to sourcing home grown timber.⁹⁷

The survey identified a number of findings;⁹⁸

- The sector [in 2007] is experiencing strong growth and demand is predicted to increase generally by 10% per annum, with a supply volume of 100,000m³ predicted to be realised in 5 years.
- The quantity of home grown timber in the current supply of materials to timber frame manufacturers is almost impossible to identify.
- 80% of the study sample had not attempted to source Welsh timber but would be prepared to if material were readily available and competitively priced. One company had advised of an attempt to establish a supply of

94 Ibid., p. 30.
95 Ibid., p. 18.
96 Ibid., p. 30.
97 Dennis Jones, *Welsh timber resources and their potential within the construction industry*, p. 24.
98 Ibid., pp. 25 - 26.

C16 through a local sawmill but failed due to ‘commercial difficulties’.

- A number of companies reported the use of home grown timber, specifically Douglas Fir for non structural purposes, reported to be Client driven.
- BSW currently produce C16 at 47mm thickness only. Manufacturers typically prefer to use 38mm thick material, primarily due to cost.
- Manufacturers reported that Specifiers and Architects are often responsible for demanding Scandinavian timber and in some circumstances the use of C24 for entire constructions.
- The survey also found that manufacturers were concerned over the density of homegrown timber in comparison with Scandinavia and Baltic grown material.

3.08.3 BARRIERS TO HOME GROWN TIMBER IN THE CONSTRUCTION INDUSTRY

The initial findings of BRE’s survey were furthered in the published report Bridging the Gap Phase 1 issued in 2007 by BRE. The report identified a number of key factors that could be seen as barriers to the use of home grown timber in the UK construction industry. Since the commencement of the Ty Unnos research study, the findings of the Bridging the Gap study have been reinforced and developed through discussions with a broad spectrum of specifiers, builders, consultants and manufacturers and the experiences of the project team in pursuing the project aims.

MARKET SATURATION

Increasing European production, to a level of 25-30% above current production by 2020, and the re-emergence of supplies from Russia and other former Soviet Union countries will effectively saturate the UK market with imported timber.⁹⁹ The effect of a saturated market will increase competition for home grown timber and continue to decrease timber values.

INCREASING DEMAND FOR WELSH TIMBER

88% of homegrown timber is currently consumed domestically in the UK,¹⁰⁰ however the UK is rated at 17th of 25 EU countries for self sufficiency, providing just 24% of the timber consumed.¹⁰¹ Sawmillers are therefore increasingly identifying specific higher value markets for homegrown material.¹⁰² An example of this is the export of Sitka Spruce wood chips and fibres to Austria and Finland for the paper industry due to the longer, whiter fibres obtained from homegrown

99 Ibid., p. 7.
100 Ibid., p. 10.
101 Ibid., p. 9.
102 Ibid., p. 11.

Strength class according to EN 338		C18 and below	Above C18
Max. permitted length of fissures ^a		Fissures less than half the thickness may be ignored	
	Fissures not going through the thickness	Not greater than 1,5 m or ½ the length of the piece, whichever is the lesser	Not greater than 1 m or ¼ the length of the piece, whichever is the lesser
	Fissures going through the thickness	Not greater than 1 m or ¼ the length of the piece, whichever is the lesser. If at the ends, a length not greater than two times the width of the piece	Only permitted at the ends with a length not greater than the width of the piece
Max. warp ^b in mm over 2 m of length	Bow	20 mm	10 mm
	Spring	12 mm	8 mm
	Twist	2 mm/25 mm width	1 mm/25 mm width
	Cup	Unrestricted	Unrestricted
Wane		Wane shall not be greater than one third of the full edge and/or face dimensions of the piece	
Soft rot and dote ^c (see EN 844-10)		Soft rot is not permitted.	Soft rot is not permitted.
		Dote is permitted	Dote is not permitted
Insect damage		No active infestation is permitted. Wood wasp holes are not permitted and worm and pin holes shall be assessed as abnormal defects	
Abnormal defects		Where the reduction in strength caused by the abnormal defect is obviously less than caused by other defects permitted by this table, the piece may be accepted provided the defect is of a type that will not increase after conversion and drying	

^a The length of fissures is linked with moisture content and therefore the limits given apply only at the time of grading. Limitations on fissures for special grades for specific components may be disregarded if research confirms that they have no effect on strength. Permitted limits for both the depth and length of fissures refer to the cumulative sum of fissures in one plane in a piece of timber.

^b Because warp is influenced by moisture content, the limits apply only at the time of grading. Limits of warp will be less if required by the method of operation of the grading machine. Longitudinal curvature in square section pieces shall be assessed using the limits for bow.

^c Sapstain is not a structural defect and is acceptable without limitation.

Table 3.13: The maximum limits for distortion permitted for timber entering the grading process, measured in accordance with EN 1310.

Source : British Standards, *BS EN 14081-1:2005 : Timber structures : Strength graded structural timber with rectangular cross section : Part 1: General requirements* (London: British Standards Institution, 2006), p. 9.

Table 3.14: The maximum limits for knot diameter and slope of grain permitted for timber entering the grading process.

Source : British Standards, *BS EN 14081-1:2005 : Timber structures : Strength graded structural timber with rectangular cross section : Part 1: General requirements* (London: British Standards Institution, 2006), p. 10.

	Strength class according to EN 338	
	C18 and below	Above C18
Knot diameter on face	½ x width of piece	¼ x width of piece
Knot diameter on edge	¾ x thickness of piece	½ x thickness of piece
Slope of grain	1 in 6	1 in 10
NOTE 1 These maximum limits are only applicable where the size of knots and slope of grain in the non-fully graded portion exceeds the size of similar characteristics in the fully graded portion of the same piece.		
NOTE 2 The knot diameter is measured perpendicular to the longitudinal axis of the piece of timber. For arris knots the above limits apply to the portion of the knot visible on the particular face or edge being considered.		

material compared to the local resources such as Norway Spruce.¹⁰³

The Bridging the Gap report suggests that Welsh timber is currently operating close to its maximum potential in terms of outputs, with the input demand for Welsh sawmills operating at 102% of the available material.¹⁰⁴

DEFORMATION OF UK GROWN TIMBER

The report finds that saw millers suggest between 10-12% of each kiln load is rejected after kiln drying due to excessive distortion.¹⁰⁵ Figure 3.25 shows the most common forms of distortion.

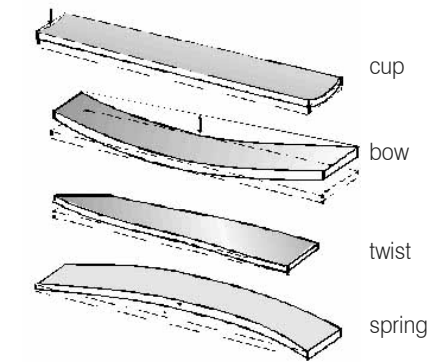


Figure 3.25: Common forms of timber deformation.
Source : Dennis Jones, *Welsh timber resources and their potential within the construction industry* (Margam: BRE Wales, 2007), p. 18.

Deformation of timber is primarily caused by stresses in the timber and shrinkage during drying. When cut and subsequently dried, residual stresses cause the timber to deform to take a shape where stresses are more evenly distributed. A number of timber characteristics can cause deformation of timber including; grain angle, annual ring curvature, density, juvenile wood, compression wood and knots.

Welsh timber is most commonly effected by compression wood, formed when a tree, particularly fast growing species, experiences pronounced external forces such as those caused by strong coastal winds on exposed hillsides.¹⁰⁶ Subsequently the tree reacts to unbalanced forces by forming additional compression wood on the opposite side of the external force to maintain a balanced alignment. Once cut however these forces are no longer retained by the full section of the tree and timbers are able to dramatically distort.

Experience with home grown timber has found the primary concern to be twisting of timber along its primary axis. The deformation can be extremely dramatic with twisting of over 90 degrees in some examples. Whilst minor distortions such as cupping can often be successfully machined out, distortions such as twisting can only be resolved by returning the timber to straight by applying considerable pressure. This is rarely acceptable for timber frame construction and distortion is often cited as the primary reason for timber frame manufacturers to reject the use of home grown timber. Distortion in service is a critical issue for structural timber, as timber installed at moisture contents of 15-20%, will continue to dry out in the heated building envelope. Unless suitably restrained, changes in moisture content in situ may cause significant deformation of timber sections and result in reduced build quality and remedial costs.

Tables 3.13 and 3.14 set out the maximum limits for distortion permitted for timber entering the grading process.

103 Ibid., p. 8.
104 Ibid., p. 14.
105 Ibid., p. 15.
106 Ibid., p. 17.

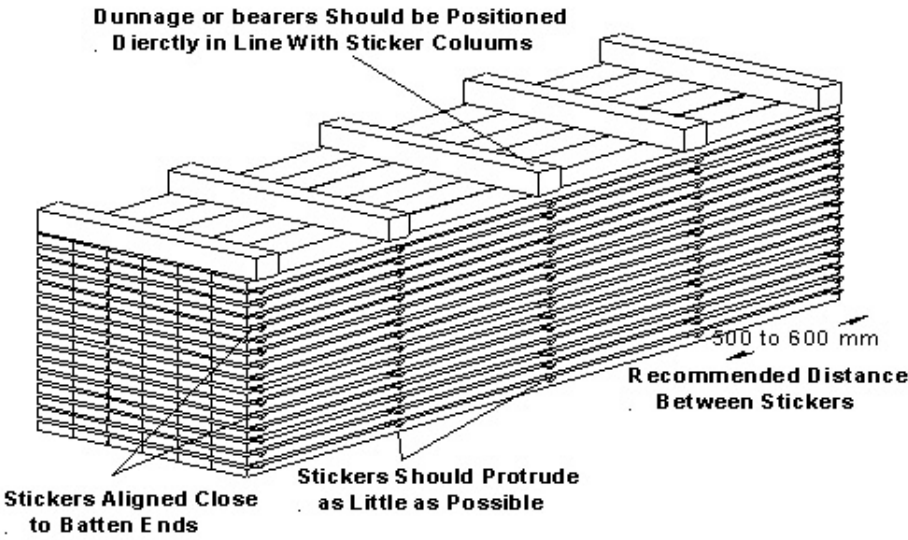


Figure 3.26: Recommended stacking system for kiln drying of large cross section material
Source : Dennis Jones, *Welsh timber resources and their potential within the construction industry* (Margam: BRE Wales, 2007) p. 18.

QUALITY AND CONSISTENCY OF WELSH TIMBER

The quality, and more specifically, the consistency of home grown timber is often considered to be lower than that of imported timber, with increased levels of distortion, broader ranges of moisture contents and some cases of biodegradation. In addition to the physical characteristics of home grown timber species, drying processes and post drying storage contribute considerably to the quality of the end product.

Pack design is considered a fundamental aspect of timber quality. Poorly prepared packs can result in an increased distortion of timber or poor results of drying processes.¹⁰⁷ Figure 3.26 shows a 'good stacking system' for kiln drying large section material. Poor stack design is often caused by;

- Inappropriate spacing of stickers, particularly for small section material, allows timbers to sag between each support, or after the edge support,
- Insufficient bearers between packs or between pack and floor resulting in the entire pack sagging,
- Multiple dimensions of timber included in each pack. This has a considerable affect on moisture content but may also cause packs to be unbalanced or poorly supported.

Perhaps most critically to application in construction is the moisture content of delivered sawnwood, which is often found to have considerable variation.¹⁰⁸ There are a number of possible explanations for variation in moisture content;

- Timber is entering the drying processes with a significant variation in moisture content, including from individual timber sources,
- Drying processes and timber packing are not resulting in consistent moisture contents throughout the kiln load,
- Timber is being re-wetted post drying due to inappropriate storage and transportation provisions.

In order to strength grade structural softwood for use in buildings, the average moisture content must be below 20% and the timber marked DRY or KD. Following drying it is essential that stamped dry timber is protected from significant wetting and high humidity as the moisture content will increase easily if stored incorrectly. In addition to concerns regarding deformation, the mechanical and physical properties of wood are dramatically affected by its moisture content. As moisture content increases hydrogen bonds within the cell wall lengthen and subsequently get weaker, causing a reduced mechanical performance. This also causes a change to the physical size of the timber section, with shrinkage or expansion typically predicted to be a 1% change in width and thickness for every

107 Ibid., p. 16.

108 Ibid., p. 16.

4% change in moisture content.

The control of moisture contents during and post drying is primarily a quality control issue. However the specification of moisture contents for use in the construction industry is becoming increasingly demanding. The National Building Specification for example recommends that moisture contents should be specified based on intended use;¹⁰⁹

- 18 per cent in covered, generally unheated spaces
- 15 per cent in covered, generally heated spaces
- 12 per cent in internal conditions: in continuously heated buildings
- 20 per cent or more for external timber.

Many of the issues concerning quality control have received considerable investment from the larger sawmills in Wales. However there appears to be a general perception in the construction industry that home grown timber is a lower quality product than imported timber. The reality seems to be that home grown timber is more sensitive to poor treatment than imported timber, therefore processes including post drying storage, transportation and on site storage must be carefully managed to ensure a high quality product can be maintained.

INCONSISTENT MIX OF TIMBER SPECIES

In addition to concern of quality and moisture content consistency, there is also concern due to the mix of species that is marketed as Welsh ‘whitewood’. Sitka Spruce is the majority species supplied as whitewood however a proportion of Douglas Fir is typically included.¹¹⁰ In addition, samples of Welsh softwood have been supplied to the project team including small quantities of Larch, Norway Spruce and Pine. All of the supplied timbers have similar strength characteristics however the workability of each species can be very different.

SOURCING AND THE SUPPLY CHAIN

There are a number of sourcing issues that seem to restrict the utilisation of home grown timber supplies for timber frame manufacture;

- Existing supply contracts with importers. Import companies aggressively pursue long term supply contracts with timber frame manufacturers to ensure consistent supplies, typically at consistent prices. Once these contracts are established it is rare for timber manufacturers to require sourcing timber from any alternative suppliers, and experience has shown that manufacturers are typically resistant to changes to established supply

109 Austin Williams, *Wooden performance: moisture content of timber* (Newcastle Upon Tyne: NBS) <<http://www.thenbs.com/topics/constructionproducts/articles/woodenPerformance.asp>> [accessed 01 July 2011]

110 Dennis Jones, *Welsh timber resources and their potential within the construction industry*, p. 24.

chains.

- Home grown timber for construction is not aggressively marketed in the same manner as imported timber. Discussions with the larger sawmills suggest that long term contracts or agreements are not encouraged by Welsh sawmills. Welsh sawmills typically supply based on the values and available stocks at any given time, therefore supply chain agreements with manufacturers are often resisted.
- Timber stocks at Welsh sawmills are extremely limited with BSW reporting a maximum of 10-12 days supply maintained at the Newbridge on Wye site and similar quantities maintained by Pontrilas Timber. This restricted level of stock reduces the ability of sawmills to respond to high demands for home grown timber and could leave them prone to supply issues following periods of bad weather for example.¹¹¹

The timber industry is a heavily fluctuating market with international, national and often regional factors affecting the values of timber. The timber industry in Wales responds considerably to this fluctuating market to maximise the often slim margins for profit available for relatively low value products. This can result in supplies being harvested early to capitalise on periods of high values, and products rationed for the most profitable markets. This inconsistent supply chain is often troublesome for secondary processors and is not conducive for large scale manufacturers such as timber frame manufacturers.

STRENGTH GRADING

Typically homegrown timber is graded to a maximum of C16. As has been discussed previously it is possible to strength grade quantities of homegrown timber to C24 however the result is a higher quantity of rejected timber therefore it is usually considered to be uneconomical by graders.

This grading limitation is exacerbated by a lack of connected thinking between specifiers and homegrown timber suppliers. In many construction scenarios C16 timber can be considered appropriate and efficient however specifiers tend to apply C24 as standard, often without recognising the affects of sourcing.¹¹² A study by BSW proposed a notional 6.26m x 3.44m first floor room and illustrated that for an imposed load class not exceeding 1.50kN/m2 designed in accordance with BS EN 336, the span could be achieved using;¹¹³

- 13 joists C24 45x170x3600 or
- 13 joists C16 45x195x3600.

The price difference between timber sizes would be negligible.

111 Ibid., p. 12.
112 E. Johnson, *British Grown C16 Timber* (Newbridge: BSW Timber) p. 16.
113 Ibid., pp. 19 - 22.

DENSITY

Of particular relevance to strength grading is the density of timber for calculation. The industry has questioned the appropriateness of the existing Sitka Spruce density as provided in the BS 5268: Part 2 Annex A at 400kg/m³. A study performed by BRE in 2000 found that from a sample of 406 specimens a weighted average density of 450.63kg/m³ was calculated.¹¹⁴ The study went on to compare graded samples against the requirements laid out in BS 5268: Part 2 Table 7 and BS EN 338 Table 1. This study found that the density differences between British grown Sitka Spruce graded for the lower strength classes, C14 to C18, were actually within 20kg/m³ of the specimens graded to C24 strength class, and in all cases the density of specimens were at least 20kg/m³ higher than target values for characteristic and mean densities.¹¹⁵ The study concluded that densities as identified by BS EN 5268 are conservative for British grown Sitka Spruce, and particularly, lower densities as identified for the lower grading classes, could directly penalise the application of Sitka Spruce in use as they are employed in the calculation of joint design.

It has often been raised in discussion that the density of home grown timber, specifically Sitka Spruce, is insufficient for many structural applications. The study would suggest that this is a limitation of the characteristic and mean densities. Industry leaders have advised that further work could be commissioned on home grown Sitka Spruce samples to challenge the accepted performance data for grading, including densities, as the performance of timber in use is often considerably better than calculation would suggest.

FOREST STEWARDSHIP COUNCIL

Whilst all timber supplied by the Forest Commission is FSC certified. The need for FSC certification can pose a considerable financial and management burden for small sawmillers and processors, and private forest owners with limited timber resources. The FSC certification system is a critical aspect of sustainable resource management however it can restrict the supply of timber of a structural quality to larger industry contributors.

WORKABILITY

Home grown timber does typically show a larger quantity and size of knotting. Whilst this does not necessarily result in a reduced workability, there is a general perception that home grown timber will place greater demands on machinery and processing, particularly in order to meet the tolerances required by timber frame manufacturers. Studies performed by BRE have found that issues such as increased fouling of nails did not occur when trialled with home grown timber

114 BRE, *Digest 445 Advances in timber grading* (Watford: BRE, 2000), p. 6.
115 Ibid., p.5.

however manufacturers remain discouraged by the perceived workability.

TREATMENT AND PRESERVATION

Home grown timber does not have sufficient natural durability for the majority of construction applications. Therefore a form of preservative treatment must be applied in order to guarantee the required life expectancy of the elements. This is not uncommon for softwood timbers in construction applications however as previously discussed, Sitka Spruce is classified in EN350-2 as being difficult to treat with preservatives. This characteristic is of concern as treated Sitka Spruce is more susceptible to damage than other timbers.

3.09 MODERN METHODS OF CONSTRUCTION

In the following section, the subject of Modern Methods of Construction will be defined, and considered in terms of the opportunities and advantages that system builds may offer when applied to the construction of housing.

The essence of ‘prefabrication’ dates back to the techniques of medieval construction with frames and joints prepared off site in the carpenter’s workshop, sometimes requiring considerable repetition, assembled and marked before being transported to site. Further back in history, the ideas of prefabrication were utilised by nomadic hunter-gatherers to create lightweight shelters of branches, leaves, furs and skins, which could be easily transported, dismantled and reassembled to provide temporary dwellings tailored to often challenging environmental conditions. However most literature on the subject identifies the 19th century boom towns of America’s mid-west and the expanding colonies of Australia and South Africa as the catalyst for developing industrialised modern off site construction techniques. Emerging materials such as rolled iron and steel, improved milling and tools, and changing availability of natural resources gave rise to many forms of innovative construction techniques.

During the 20th Century approximately 1 million homes have been realised in the UK through the use of prefabrication and off site construction.¹¹⁶ Often constructed as temporary solutions, prefabricated homes have been employed at periods throughout the century in direct response to critical housing shortages. Many prefabricated homes were maintained and inhabited way beyond their short design lives and subsequently prefabricated homes have become associated in the UK with poor quality, workmanship and durability.

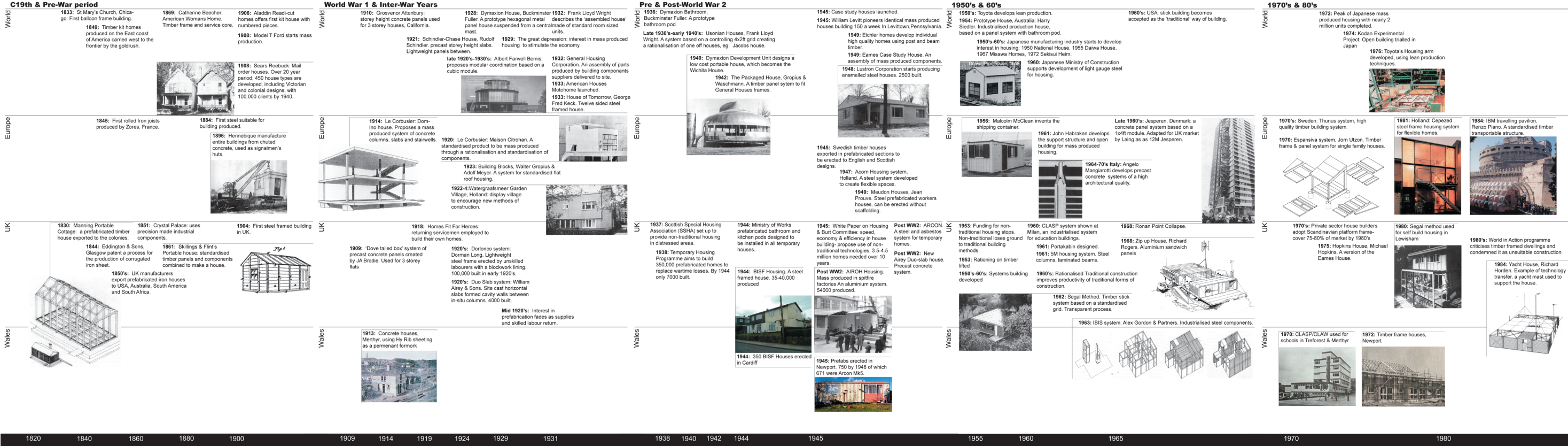
The term ‘Modern Methods of Construction’ (MMC) has been introduced in the last two decades to encourage a new public confidence in prefabricated construction techniques by highlighting the technical and material innovation that is now enables the construction and manufacturing industries to offer strong alternatives to traditional on site construction techniques.

Figure 3.27 shows a study produced by the Design Research Unit Wales with BRE Wales to chart the key developments in Modern Methods of Construction. It identifies a number of relevant precedents in system design and of equal interest in the experience of others in the development of innovative construction systems. The history of MMC and specifically MMC for the application of constructing homes, presents a varied mix of fortune, illustrated in great detail by Colin Davies in ‘*The Prefabricated Home*’. In order to identify opportunities for a whole house system design, a broad consideration of the subject area of MMC

116 Parliamentary Office of Science and Technology, *Postnote : Modern Methods of House Building* (London: Parliamentary Office of Science and Technology, 2003), p. 1.

and prefabricated homes has been wise and useful. Whilst it is not relevant to reflect in great detail on this subject, there are a number of key precedents and lessons which have emerged as essential guidance for future direction.

Figure 3.27: Key national and international developments in the subject of prefabrication and Modern Methods of Construction.
Source : Design Research Unit Wales, MMC Wales : Achieving Modern Methods of Construction in Wales (Cardiff: Welsh School of Architecture, 2008), pp. 4 - 5.



3.09.1 DEFINING MODERN METHODS OF CONSTRUCTION

In 2003 the Housing Corporation, the operating non-departmental body responsible for affordable housing, published a classification system for construction methods in order to award grants for new housing. The system was based on 5 product categories,¹¹⁷

- 1. Volumetric off site manufactured,
- 2. Panellised off site manufactured,
- 3. Hybrid off site manufactured,
- 4. Sub Assemblies + components
- 5. Non off site construction

The Office of the Deputy Prime Minister subsequently adopted the system for classification in the *Housing, Planning, Local Government and the Regions Select Committee - Eighth Report; July 2004*, and the system has been used to define MMC in most subsequent studies.

Defining MMC in terms of products however can be considered to be restrictive as MMC could also include innovative work processes and management systems, that improve efficiency and quality both on site and off site. In October 2006 the Barker 33 Cross Industry Group expanded on the ODPM definition with the statement,

*Modern Methods of Construction are about better products and processes. They aim to improve business efficiency, quality, customer satisfaction, environmental performance, sustainability and the predictability of delivery timescales. Modern Methods of Construction are, therefore, more broadly based than a particular focus on product. They engage people to seek improvement, through better processes, in the delivery and performance of construction.*¹¹⁸

MMC can therefore be considered as those that utilise innovation, and production and management efficiency measures to provide more products of a better general quality in less time than traditional methods of construction.

*Modern Methods of Construction (MMC) are defined as those which provide an efficient product management process to provide more products of better quality in less time. It has been defined in various ways: pre-fabrication, off-site production and off-site manufacturing (OSM). But while all OSM is MMC not all MMC is OSM. It can be classified in various ways and may involve key services (e.g.) plumbing, key items (e.g. foundations) inner shell (walls etc), external walls, or any combination of these elements. It can also be classified by material (timber, steel, concrete and masonry).*¹¹⁹

Alternative definitions may also extend to include innovative on site construction techniques, however the primary focus of this research study is the employment

117 NHBC, *A guide to modern methods of construction* (Amersham: NHBC, 2006), p. 3.
118 Barker 33 Cross-Industry Group, *Modern Methods Of Construction : Executive Summary Of Final Report* (Barker 33 Cross-Industry Group, 2006), p. 6.
119 BURA, *Modern Methods of Construction : Evolution or Revolution?* (London: BURA, 2005), p. 9.

of innovation and off site pre-fabrication to produce high quality and low cost construction components to realise more homes at lower cost and improved buildability.

VOLUMETRIC CONSTRUCTION

Volumetric or Modular construction are systems that employ off site manufacturing conditions to produce three dimensional units for transportation and assembly on site. Typically 80-95% of the construction tasks involved in volumetric units are completed off site within factory conditions, including wet trades and finishes.¹²⁰ All services are typically installed and tested during fabrication and therefore only require onsite connection to the mains supplies.

Although Volumetric construction offers great potential for realising affordable homes using homegrown timber, this study is not going to address the opportunity for a Volumetric system. This development thread has been embarked upon for commercial application by Elements Europe in collaboration with the Project Team. However volumetric construction does not suitably address the objectives of this research study. Most notably the objective to offer a flexible construction solution suitable for a diverse range of small, low capacity rural development sites and employing manufacturing skills and processes which are broadly appropriate to the existing timber industry in Wales. Opportunities for a volumetric solution will therefore not be considered within the scope of this study.

3.09.2 THE ADVANTAGES OF MMC

SKILLS

- It is generally recognised that construction skills are in decline due to;
- A large gap of employees in the 26-45 year age range making transfer of knowledge throughout the demographic significantly challenging,
 - generally poor performance of training initiatives have resulted in high drop outs and limited commercial support,
 - reliance predominantly on contract labour reduces commitment, consistency and quality.

A 2005 study by the Construction Skills Network highlighted major shortages in construction skills in the UK finding that 88000 new workers would need to be recruited by the industry annually in the period 2008-12 in order to meet demand.¹²¹In Wales it is forecasted that 4750 new recruits will be required annually between 2006 and 2012.¹²²

The majority of MMC employ some form of off-site manufacture with up to 80-

120 Ibid., p. 10.
121 Construction Skills, *Construction Skills Network Wales : Labour Market Intelligence 2008 - 2012* (Bridgend: Construction Skills, 2005), p. 1.
122 Ibid., p. 1.

95% of the construction tasks completed in factory conditions. This displacement of processes to controlled factory conditions, and the subsequent decrease in the impact of seasonality on workload, can enable the potential to employ a consistent, directly employed and trained labour force. As construction tasks are translated into manufacturing processes within controlled factory conditions there is greater opportunity for employment equality and the potential to encourage a broader pool of recruits which would otherwise be overlooked for traditional on site construction.¹²³

LABOUR

In 2005 the National Audit Office published *Using Modern Methods of Construction to Build Homes More Quickly and Efficiently*. It’s findings suggest that MMC should enable the construction of 4 times as many homes using the same onsite labour.¹²⁴

Process plans designed for alternative construction systems proposed that open panel systems could reduce labour days to just over 80% and the construction period to under 80% of the time required for traditional brick and block, approximately 30 weeks. Most significant is the reduction of time taken to complete a weather tight envelope which is approximated at 55% of the time taken to achieve in brick and block.¹²⁵

The *Design for Manufacture: Lessons Learnt 2* document published in March 2010 provides detailed breakdowns of 10 MMC construction sites, including cost, construction and quality assessments of the alternative construction systems employed. Analysis of a panellised timber frame construction at School Road, Hastings including floor and roof panels and an external timber cladding allowed a 10 week manufacturing period, 2-4 days for on site erection, and 6-8 weeks fit out. See Chart 3.5. This equates to a 50% reduction per dwelling on traditional construction times.¹²⁶

QUALITY

Generally there is a perception that build quality in domestic construction is declining. Studies performed by the Home Builders Federation and the Office of Fair Trading present statistical data to suggest low levels of satisfaction for homebuyers, and a high rate of problems reported following occupation.¹²⁷

The National Audit Office state that “*factory production should reduce the risk of*

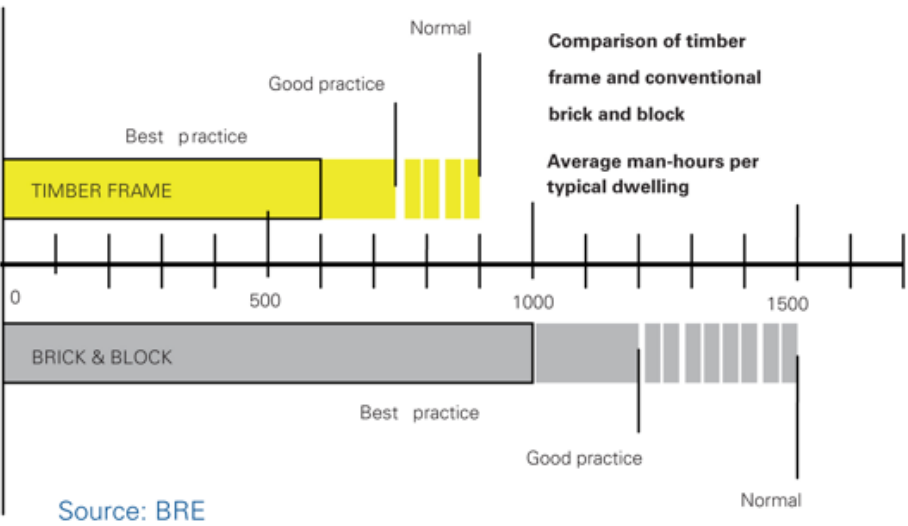


Chart 3.5: Comparison of construction types in terms of site man-hours for the construction of a typical dwelling.
Source : Homes and Communities Agency, *Designed for Manufacture: Lessons Learnt 2* (London: Homes and Communities Agency, 2010), p. 57.

123 National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently* (London: National Audit Office, 2005), p. 7.
124 Ibid., p. 7.
125 Ibid., p. 8.
126 Homes and Communities Agency, *Designed for Manufacture: Lessons Learnt 2* (London: Homes and Communities Agency, 2010), p. 53.
127 Office of Fair Trading, *Homebuilding market study : Annexe B – New homebuild consumer survey - report on findings* (London: Office of Fair Trading, 2008), pp. 9 - 13.

non- conformities, related premature failures and consequent repairs which may be associated with on-site assembly”.¹²⁸ MMC offers great potential for reducing defects. The manufacture of construction components in controlled factory environments can offer a great potential for implementing tight quality control measures, far beyond the levels that can be efficiently realised with traditional onsite construction.¹²⁹ Of particular value is the increased protection from the effects of weather that the prefabrication of components can enable.

WASTE

In June 2010 the WAG launched the Towards Zero Waste Strategy, identifying a number of targets specifically aimed at the construction industry;¹³⁰

- 90% of waste generated by the construction industry must be recycled or reused by 2025,
- a 1.4% annual reduction of waste from the 2007 benchmark.

The use of MMC and production of construction components off site enable a considerable opportunity for reducing waste as;

- Manufacturers are directly responsible for sourcing therefore efficiency in the supply chain and manufacturing achieves immediate cost benefits,
- Close management of assembly lines and manufacturing processes can enable identification of wasteful processes and efficiency improvements,
- Materials can be stored, processed and transported in controlled and protected surroundings to reduce waste caused by weather damage,
- Waste management plans can be introduced and controlled in factory conditions including developing strategies and agreements with waste management companies,
- MMC products can source cut to size products and tailor designs and processes to standardised products, such as standard wood panel sizes, to reduce the production of waste.

The BRE SMARTlife project recorded waste assessments arising on site and during factory based manufacture for the construction of 106 new homes using 3 different MMC systems and traditional brick and block. The study found that the construction of timber frame homes resulted in an 11% waste reduction compared to traditional brick and block, or 19.16m³ of waste generated for every 100m² of floor area. Steel frame construction generated 16.84m³ per 100m², a 22% waste reduction and Volumetric steel resulted in just 5.51m³ per 100m².¹³¹

128 National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently*, p. 12.

129 Ibid., p. 18.

130 Welsh Assembly Government, *Towards Zero Waste: Summary* (Cardiff: Welsh Assembly Government, 2009), p. 4.

131 BeAware, *BeAware Supply Chain Resource Efficiency Sector Report : Modern Methods of Construction* (Watford: BRE), p. 3.

HEALTH AND SAFETY

Statistics published by the Health and Safety Executive show that there were 42 fatal injuries to construction workers in 2009/2010, accounting for the highest rate of fatality of all the major industry groups. In addition the HSE also report that there were 230 major injuries per 100 000 employees in 2009/10. The HSE identifies handling as responsible for 28.9% of injuries, with 22.3% due to slips and trips and 1435 injuries resulting from falls.¹³²

Although rates are steadily decreasing, with major injuries falling 34% since 2000 and fatalities by 47%, construction is still the most dangerous industry on paper.

The *Design for Manufacture: Lessons Learnt 2* study provides an evidence based assessment of health and safety experienced across four development sites. The number of reported non fatal injuries across the sites was at an average of 0.57 per 100 workers, approximately 25% lower than the 2006/07 industry rate of 0.9%.¹³³ Of particular note was the very limited requirement for scaffolding and working at height, thanks to the use of panel and cassette systems.¹³⁴

The increased use of factory based manufacturing processes associated with MMC can significantly reduce the risk of construction related injuries. Controlled working environments, reduced working at height, reduced demand of manual handling and increased familiarity offers significantly improved Health and Safety conditions. However this improvement relies considerably on the application of appropriate health and safety plans and assessments, including on and off site training, as there will be a higher risk associated with new working practices.

132 Health and Safety Executive, *Construction Industry* (London: Health and Safety Executive, 2011) <<http://www.hse.gov.uk/statistics/industry/construction/injuries.htm>> [accessed July 2011]
133 Homes and Communities Agency, *Designed for Manufacture: Lessens Learnt 2*, p. 13.
134 Ibid., p. 83.

3.10 MODERN METHODS OF TIMBER CONSTRUCTION

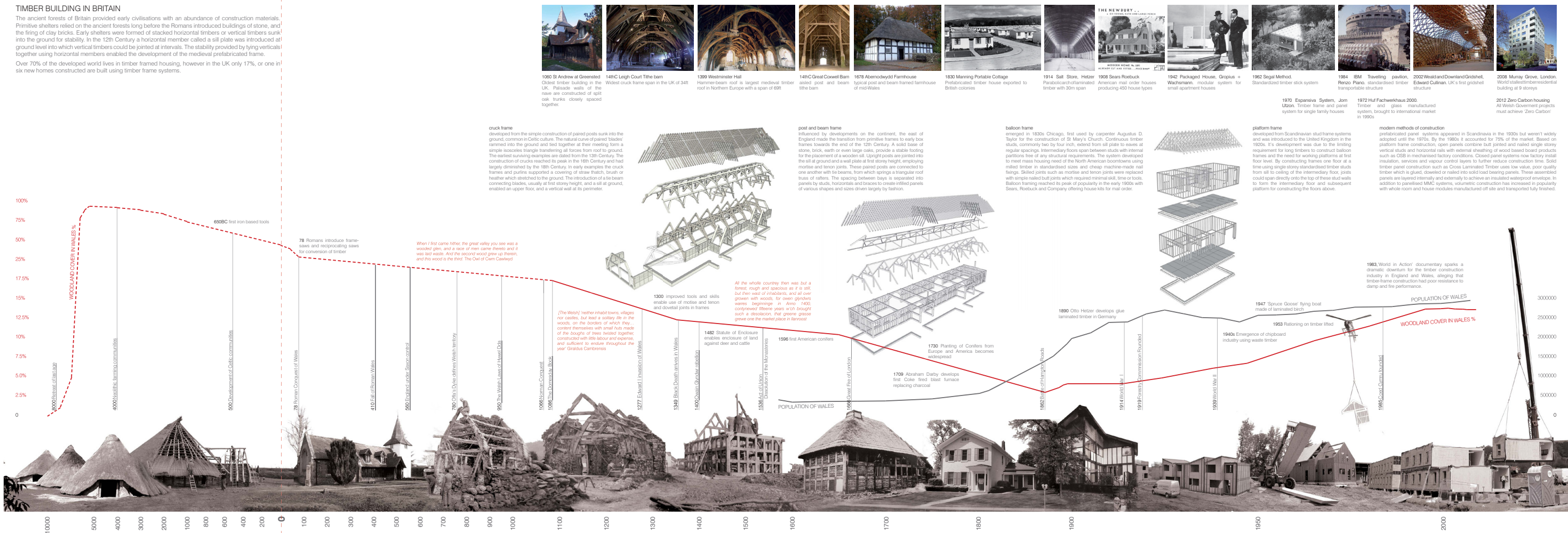
In their publication *Off Site and Modern Methods of Timber Construction*, TRADA describe and categorise modern methods of timber construction using a concise illustration of the evolution of modern methods of timber construction from four traditional forms of construction originating predominantly in Europe;¹³⁵

- Cruck Construction
- Box Frame Construction
- Post and Truss Construction
- and Massive Timber Construction

In order to consider the potential development routes for a homegrown timber construction system, a brief study of MMC and MMC timber systems has been performed. The first stage of this considers the TRADA categorisation system described above. Each evolution type is analysed in terms of structural philosophy and a number of historical and contemporary precedents are identified. A summary of this analysis can be seen in Table 3.15. The primary purpose of this study is to learn from existing products and methodologies and identify potential opportunities for technology transfer.

Figure 3.28: Key national and international developments in the timber frame construction industry plotted against timber production in the United Kingdom. Generated for exhibition at the Welsh Folklife Festival at the Smithsonian Institute, Washington.

135 Robert Hairstans, *Off-site and Modern Methods of Timber Construction*, pp. 15 - 16.



OPPOSITE PAGE

Table 3.15: National and International Precedent construction systems by TRADA Structural Categorisation

TRADA CATEGORIZATION	STRUCTURAL EVOLUTION	STRUCTURAL PHILOSOPHY	PRECEDENT STUDIES	DESCRIPTION	STRENGTHS	WEAKNESSES
POST + BEAM FRAME	 Duck Frame	A structural frame of timber members are spaced at wide centres to form 'bays' with dimensions determined by the load bearing capacity of the large section posts and beams Each primary timber has a distinct structural function and is commonly required to transfer considerable forces from roof to foundation. They are typically constructed from large and strong sections of timber with high structural capacities. The spacing between structural members is infilled with non loadbearing panels designed to deal primarily with the control of weather. The specification and design of internal and external walls therefore have great flexibility and freedom.	1942 General Panel System Konrad Weichsmann & Walter Gropius	A system of 40x20 inch panels that can be combined in a variety of ways to create a temporary house in which Segal set out to simplify the construction process, and later a method of building to create a permanent, affordable housing project. The system is essentially a post and beam frame using connections. The frame is arranged into portal frames set at 600mm or 1200mm centres to be infilled with non load bearing infill panels and set on lightweight foundations with a suspended timber floor.	1942 General Panel System Konrad Weichsmann & Walter Gropius	1942 General Panel System Konrad Weichsmann & Walter Gropius
	 Post and Truss Frame		1970 Espansvia System Jorn Utzon	Designed as a series of single storey spatial elements that correspond to typical domestic spaces. Each unit is joined using a universal X shaped wedge connector that enabled any combination of panels. The system is essentially a post and beam frame using connections. The frame is arranged into portal frames set at 600mm or 1200mm centres to be infilled with non load bearing infill panels and set on lightweight foundations with a suspended timber floor.	1970 Espansvia System Jorn Utzon	1970 Espansvia System Jorn Utzon
	 Modern Post and Beam Frame		1970 Segal Method Walter Segal	The Segal method emerged from the construction of a temporary house in which Segal set out to simplify the construction process, and later a method of building to create a permanent, affordable housing project. The system is essentially a post and beam frame using connections. The frame is arranged into portal frames set at 600mm or 1200mm centres to be infilled with non load bearing infill panels and set on lightweight foundations with a suspended timber floor.	1970 Segal Method Walter Segal	1970 Segal Method Walter Segal
PLATFORM FRAME CONSTRUCTION	 Box Frame	Many small evenly spaced vertical members are located at close intervals throughout the wall length to provide continuous support for a horizontal wall plate onto which bears floor joists and further wall panels or a system of lightweight evenly spaced structural roof members, typically in the form of a truss. The continuous support provided by typically single storey vertical studs allows floor and roof loads to be distributed equally along the full wall length and transmitted into a continuous foundation.	Contemporary RuralZed Zed Factory	Model combine cellulose insulations such as straw bales and hemp with large glulam timber sections to form single story prefabricated panels typically to 3 x 2m dimensions and a thermal envelope of 300mm thick hardwood insulation.	Contemporary RuralZed Zed Factory	Contemporary RuralZed Zed Factory
	 Balloon Frame		Contemporary Modell White Design	Model combine cellulose insulations such as straw bales and hemp with large glulam timber sections to form single story prefabricated panels typically to 3 x 2m dimensions and a thermal envelope of 300mm thick hardwood insulation.	Contemporary Modell White Design	Contemporary Modell White Design
	 Platform Frame		1895 Modern Homes Sears, Roebuck and Co	Until 1926, when Sears expanded into steel framing, the platform frame system was the dominant form of construction for single story houses. The system consists of a platform frame system (sills, joists, and studs) on which the walls and roof are built. The system is characterized by its simplicity and its ability to be built by a small crew of eight workers and just a hammer.	1895 Modern Homes Sears, Roebuck and Co	1895 Modern Homes Sears, Roebuck and Co
MASSIVE TIMBER CONSTRUCTION	 Open or Closed Panel	Many sections of timber are combined to form a panel of solid timber. All loads are distributed equally through the entire wall panel with all timber sections typically acting in equal compression. In log on log construction, glues, dowels and section profiles can provide additional stability, however loads can be successfully transferred through the simple stacking of materials. In the case of CLT, whole wall sections act as one element due to the bonding of many small timber elements. It is increasingly common for CLT to also provide floor and roof solutions, removing the need for many individual timber sections in the form of floor beams or tussled rafters.	Contemporary Space 4 Perrinsson Homes	Space4 employs automated CNC/CAM production processes to manufacture a patented closed panel timber frame system (sills, joists, and studs) on which the walls and roof are built. The system is characterized by its simplicity and its ability to be built by a small crew of eight workers and just a hammer.	Contemporary Space 4 Perrinsson Homes	Contemporary Space 4 Perrinsson Homes
	 Round Log		Contemporary Stewart Milne Timber Systems	Stewart Milne Timber Systems offer a wide range of closed panel timber frame systems including the Prototype Generation 3 closed panel system which consists of 140mm x 60x38mm treated saw studs with 10mm cement particle board or OSB3 sheathing, a vapour barrier and injected phenolic foam insulation to give a standard U value of 0.29W/m2K, and floor cassettes of 22mm chipboard on 240mm engineered TJI or BC joists.	Contemporary Stewart Milne Timber Systems	Contemporary Stewart Milne Timber Systems
	 Square Log		Contemporary EURBAN	Specialist timber contractor Eurban supply a range of Cross Laminated Timber panel products. All employ a similar construction method using a combination of glues, dowels and section profiles can provide additional stability, however loads can be successfully transferred through the simple stacking of materials.	Contemporary EURBAN	Contemporary EURBAN
ALTERNATIVE CONSTRUCTION METHODS	 Cross Laminated Timber	Structurally Insulated Panels fall between massive timber construction and panel construction in their structural philosophy. SIPs are panels consisting of an insulating expanded or extruded polystyrene or polyurethane core laminated between two sheaths of plywood or OSB. The panels perform in a similar manner to an I section beam, with the outer layers acting as continuous flanges under stress, connected by a continuous web of rigid insulation. SIPs can provide all main structural elements, including pitched roofs, for constructions up to 4 storeys.	Contemporary Kingspan Tek	Kingspan TEK is a SIPs panel system comprising of a top layer of 15mm OSB3, a 100mm thick polyisocyanurate (PIR) insulation core, and a basic U value of 0.21W/m2K. Panels have a routed channel along each edge into which fits an insulated joining cassette. Panels are suitable for load bearing and non-load bearing applications and are available in a range of sizes from 1200x2400mm up to 2400x4800mm. The system uses a number of 'cores' with flat or pitched roofs applied which can be combined to form a wide range of configurations.	Contemporary Kingspan Tek	Contemporary Kingspan Tek
	 Round Log		Contemporary STEKO	STEKO is a Swiss construction system consisting of a kit of hollow blocks designed to stack together in a running bond to form internal and external walls. A range of modules are based on a standard module of 640x260x40mm. Wall dimensions and openings are determined by the standard dimensions of the modules. The system uses a number of 'cores' with flat or pitched roofs applied which can be combined to form a wide range of configurations.	Contemporary STEKO	Contemporary STEKO
	 Square Log		Contemporary Lignatur The Bargent House by Dieter Thiel	Lignatur is a Swiss manufacturer of prefabricated floor and roof elements consisting of large section Spruce formed into hollow box sections that are suitable for spans up to 12m. The prefabricated Box Elements are manufactured to a width of 200mm and a depth range of 120 - 320mm. They are profiled with brigs and grooves to allow boxes to be joined together in a running bond. The system uses a number of 'cores' with flat or pitched roofs applied which can be combined to form a wide range of configurations.	Contemporary Lignatur The Bargent House by Dieter Thiel	Contemporary Lignatur The Bargent House by Dieter Thiel

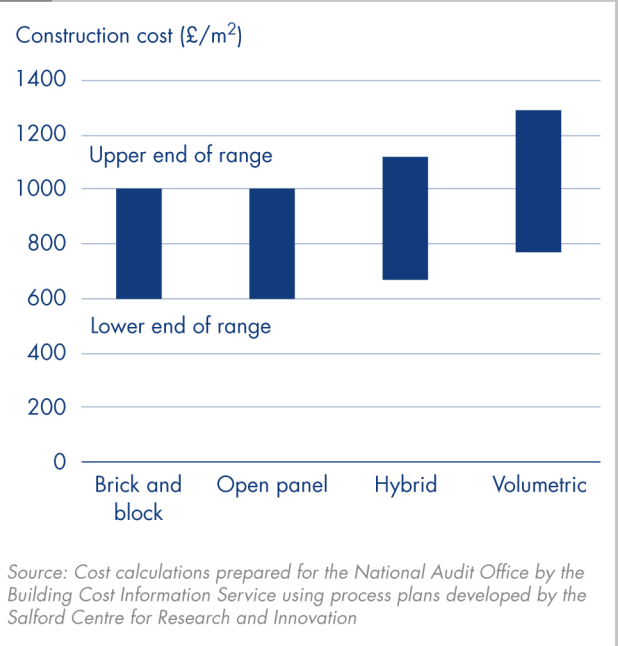
3.10.1 IN SUMMARY

Each precedent and construction type has not been reflected upon in great detail here, however the detailed analysis and consideration of each has established a broad knowledge base of technologies, approaches and experiences, which will be employed throughout the study.

There are however a number of particularly relevant findings that are worth drawing attention to;

- The approach to the design and assembly of Espansiva, employing a structural arrangement which combines the opportunity for an ‘Additive’ approach to the design of housing, with a great emphasis placed on simplifying the processes involved in construction.
- The relative complexity employed in both the manufacturing and construction detailing of the General Panel System, in order to simplify the construction process, which largely resulted in the systems commercial failure.
- The design of the Steko construction system which employs a very limited palette of small, man hand-able components which are simply combined and due to the scale of the components are capable of enabling a relatively free approach to design.
- Although the technology of SIPs systems are unlikely to be replicable in a homegrown timber system, they are becoming an increasingly important element of the domestic construction industry as they offer an innovative, high performance and entirely offsite manufactured system for realising whole house construction in a single technology type. The buildability and performance qualities, most notably airtightness and U-values, associated with SIPs systems should therefore be considered a benchmark for any MMC system utilising natural products to ensure future proofing.
- The broad variety of precedents have demonstrated a range of alternative approaches to dimensional coordination. These will be considered in greater detail when informing the design of a pattern book in Chapter 6.0.

7 Modern methods of construction tend to be more expensive than more established techniques but the ranges overlap



NOTE
Cost is calculated from the process model for a range of suppliers for each method. The average cost is then converted to a range based on the inter-quartile range of a survey of projects – the costs shown cover dwellings only, with preliminaries allocated between dwellings and external works in proportion to costs incurred before adding preliminaries. The more detailed report from the Building Cost Information Service describing these calculations is on our website and the accompanying CD-ROM.
Advanced panel methods give similar results to hybrid techniques in this particular development.

Chart 3.6: Cost comparison of Modern Methods of Construction types.
Source : National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently* (London: National Audit Office, 2005), p. 14.

Panel Type	Capital cost range £/m² floor area
Structural insulated panels comprising oriented stand board OSB/3 skins to EN 300 minimum 15mm thick, polystyrene insulation core to EN 13163 or 13164, minimum 100mm thick. Open panels.	170 – 240
Timber frame panels comprising structural grade timbers grade TR26 cross section 47mm x 97mm. Oriented stand board OSB/3 to EN 300 sheathing minimum 15mm thick. Open panels.	100 – 150
Light weight steel frame panels comprising cold formed steel sections mild steel to EN 10147 with minimum of 275g/m² zinc galvanising. Open panels.	100 – 150
Engineered laminated timber panels comprising 85mm thick cross laminated solid timber strips. Open panels.	120 – 280
Concrete wall panels comprising composite structure of concrete, reinforcement, insulation and facing brick slips. Concrete walls to BS 8110. Closed system including weathering envelope and internal partitions.	450 – 650

Table 3.16: Cost comparison of panellised system types.
Source : Peter Mayer, *Durability - Prefabricated structural panels* (London: Building, 2005) <<http://www.greenspec.co.uk/prefabricated-structural-panels.php>> [accessed 14 May 2011]

3.11 BARRIERS TO MODERN METHODS OF CONSTRUCTION

The final stage of this study into Modern methods of Timber Construction is an analysis of the key barriers that must be addressed in order for a system to realise a positive position within the industry. This analysis considers a number of key studies into the subject in recent years including the National Audit Office’s *Using MMC to Build Homes More Quickly and Efficiently*.

COSTS

The 2004 Barker Review stated;
*“At the present time, traditional brick and block methods of construction remain cheaper, in many cases, than modern methods of construction, including off-site manufacture. The time savings available do not currently provide a compelling financial reason to switch production.”*¹³⁶

This statement is reinforced by the NAO study *Using MMC to Build Homes More Quickly and Efficiently*, which found that on average MMC is more expensive than construction with brick and block, a view shared by 68% of the UK’s leading housebuilders.¹³⁷ The NAO study does however find considerable overlap between cost ranges when comparing traditional brick and block with volumetric, hybrid and open panel systems, see chart 3.6. This demonstrates that within certain project conditions it is possible for MMC solutions to be at least as competitive as traditional techniques. The chart shows that of the three MMC types, open panel systems are on average currently the most competitive.

Construction costs_ A simple analysis of the cost of each technology to supply however does not represent a fair reflection of the true costs of alternative construction types. The NAO suggest that faster construction can achieve financial benefits equivalent to a third of the additional average cost of volumetric and hybrid systems and make open panel techniques more cost effective overall than traditional construction.¹³⁸

For the construction of high density and multiple unit constructions, where developers are required to complete whole developments prior to occupation, the financing of developments for an extended construction period can pose considerable challenges for developers. As developers are at greatest financial risk whilst on site, the reduced construction period offered by MMC systems can offer significant reductions to finance costs.

136 Kate Barker, *Review of Housing Supply: Delivering Stability – Securing our Future Housing Needs* (Norwich: Her Majesty’s Stationary Office, 2004), p.113.
137 Wei Pan, Alistair Gibb & Andrew Dainty, *Offsite modern methods of construction in housebuilding, perspectives and practices of leading UK housebuilders* (Loughborough: BuildOffsite, 2005), p. 7.
138 National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently*, p. 14.

Whole life costs_ Cost assessments however must take into account whole life construction costs, of which quality of construction is a critical factor. MMC systems can offer significant reductions in the requirement for onsite inspection, snagging, and quality related defects due to the increased level of quality control and pre delivery inspections that can be integrated effectively into manufacturing processes.

However latent and systematic defects are cited by insurance and warranty providers as being of great concern in innovative systems, with the potential for a disproportionately high number of claims.¹³⁹ The history of MMC has demonstrated a number of catastrophic failures of prefabrication, and it is paralleled in other manufacturing industries such as the car industry, where batch recalls due to faulty workmanship, specification or materials has resulted in costly remedial work and lost sales. Quality control, testing and certification must therefore form a key element of system development to minimise the risks associated with systematic defects.

Commercial costs_ In addition to the costs associated directly with the construction of alternative construction types, it is also worth drawing attention to the costs associated with the bringing to market of innovative construction methods.

Start up costs for MMC systems are typically high, requiring significant investment in product development, testing and certification, manufacturing facilities and equipment, training and marketing. The Parliamentary Office of Science and Technology found that the establishment of suitable MMC manufacturing facilities and trained staff would cost over £10 million.¹⁴⁰ This is clearly a major barrier to the development of innovative systems. The objectives of this study will look to specifically address this barrier however by encouraging an evolution of existing resources, processes and businesses rather than a revolution. This must reflect a proportionate response to the proposed market application, with production quantities looking to address a relatively small proportion of the housing market.

ACCREDITATION, FINANCE AND INSURANCE

Historically, prefabrication has been associated with a number of issues related to product lifespan, durability, product defects and repair costs, which has resulted in some lenders taking a cautious approach to mortgage provision on non traditional new build.

By its very nature, MMC challenge existing construction practices, applying innovation, new technologies and new materials to offer alternative methods

139 Keith Ross, *Non-traditional housing in the UK – A brief review* (London: Council of Mortgage Lenders, 2002), p.28.

140 Parliamentary Office of Science and Technology, *Postnote : Modern Methods of House Building*, p. 3.

of construction. In doing so however it steps outside of the industry's area of knowledge where research and development, testing and decades of experience has established a strong evidence base to support an understanding of how a building is going to perform throughout its lifespan. Based on this evidence, finance, insurance and warranty providers are able to assess and manage risk, whole life costs and building performance and, with the application of minimum standards, control and improve elements of risk that are of greatest concern to them. Many forms of MMC do not have this evidence base in use therefore service providers look to independent certification and accreditation to help form a reasonable assessment of risk. However the system of accreditation can be a long and expensive process, taking over a year and costing up to £100,000.¹⁴¹

PUBLIC SCEPTICISM

Prefabrication has a chequered history in the UK. Between 1944 and 1951 the Ministry of Works Temporary Housing Programme constructed over 150,000 houses, typically designed with an intended life span of 10-15 years. However many stayed in use far beyond their intended design life and consequently the general public and media have developed a close association between poor quality and prefabrication. Events such as the Ronan Point disaster in 1968, the socially challenged high density housing of the 1960s, and damning reports of the timber construction industry by the World in Action series compounded this public perception of prefabrication.

In 2001 a survey by market research agency MORI reflected public opinion finding that 69% of respondents felt that traditional brick construction would fetch a better price.¹⁴² This market dominance of brick is still maintained in the industry 10 years on despite MMC developing a stronger market hold. Brick however is now increasingly applied as a camouflage, successfully disguising MMC structures of timber or lightweight steel frame behind a 'traditional' non-structural brick skin.

Social housing_ Over the past decade a number of government initiatives have seen MMC employed for the delivery of up to 40% of social housing programmes in the UK. Uptake in the private sector has been more reserved, leading to a concern in the industry that MMC is becoming closely associated with social housing- an association which is still seen as divisive in some sectors of the market and construction industry.

Design flexibility and repetition_ MMC performs most efficiently when standardisation and repetition is maximised. The construction industry, media

141 Ibid., p. 3.
142 MORI, *Attitudes Towards House Construction Year 2001* (London: Ipsos MORI, 2001) <<http://www.ipsos-mori.com/researchpublications/researcharchive/1422/Attitudes-Towards-House-Construction-Year-2001.aspx>> [accessed May 2011]

and the general public have interpreted this specification to mean that choice, flexibility, individuality, and design are all limited by the application of MMC systems. In some cases this may be accurate, the larger the components employed, the more cost effective a greater standardisation of plans, built forms, and materials can be. This is perhaps best reflected by volumetric systems employed for hotels and student accommodations constructed across the country with little regard for design and the local context. MMC does not however have to limit choice, individuality or flexibility, and may, if employed correctly, provide the opportunity for greater design flexibility.

DESIGN AND CONSTRUCTION PROCESS

Although considerable time savings are possible using MMC, they can only be achieved with the strict application of efficient process planning including the early integration of construction systems and a much earlier freeze on design than typically required by on site construction.¹⁴³ This requires a considerably different design and construction process, typically with an increased design period, manufacturing lead in time and earlier procurement and payment dates.

INDUSTRY CAPACITY

A study performed in 2003 by Imperial College London Innovation Studies Centre found that there were 30 house building factories operating in the UK with capacity to produce over 30,000 homes per year, approximately 17% of new housing starts.¹⁴⁴ Minor modifications, including alternative shift patterns, could increase capacity however due to the high levels of investment required for new facilities, the increase of industry capacity in order to increase market share substantially will require significant investment.

143 National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently*, p. 21.

144 Parliamentary Office of Science and Technology, *Postnote : Modern Methods of House Building*, p. 3.

3.12 SUMMARY OF FINDINGS

It can be summarised that;

- There is a crop of homegrown softwood, primarily Sitka Spruce, which is readily available in two forms; as structural carcassing timber in thicknesses of 47 or 75mm with widths ranging from 75mm to 250mm, and as falling boards in thicknesses of 16, 19 and 22mm and widths from 75mm to 200mm. In both cases a maximum length of 4.8m is common.
- Homegrown timber resources are in high demand from a range of industries, however existing products realise relatively low values. Subsequently, the Forestry Commission Wales, as primary producer, requires significant public funding in the region of £20 million per annum to subsidise the production of 1 million cubic metres of softwood.¹⁴⁵ This subsidy enables restocking to maintain woodland areas, however it does not extend to new areas of planting and has limited capacity to promote the extension of indigenous broadleaf species.
- It is recognised generally by the industry, that in order to encourage a sustainable and efficient forest industry with capacity to maintain and improve current woodland resources, alternative markets must be developed which give added value to homegrown timber at all stages of the supply chain. A number of studies have considered the potential applications for homegrown timber and it is generally recognised that the construction industry offers considerable potential for growth due to the scale and value of the whole supply chain.
- The timber frame construction industry currently accounts for 25% of all housing starts in the UK, and nearly 60% of all affordable housing units. However homegrown timber is not currently utilised in great quantity by the construction industry in the UK, particularly in England and Wales.
- There are a number of recurring barriers to its application including, a limited strength grading of C16, which is rarely specified by architects and specifiers, and the increasing availability of good quality and consistent imported timber which is available with extremely competitive terms of agreement. However it is the tendency for home grown timber to distort, specifically in the form of twisting, that is identified as the primary reason for its rejection by timber frame panel manufacturers.
- Modern Methods of Timber Construction can offer an unrivalled environmental and sustainable case, particularly when applied to housing. There are distinct benefits associated with MMC in general, including; improved quality, reduced onsite construction time, cost reductions due

145 David Jenkins and Haf Roberts, *The Value of Homegrown Timber in the Welsh Economy* (Tregynon: Coed Cymru, 2012), pp.1-2.

to economies of standardised units, improved health and safety profiles of onsite and offsite processes and reduced waste. In addition, timber can offer considerable benefits over alternative MMC systems, including significant reductions to embodied energy and Carbon Dioxide emissions.

It can be concluded that in order for home grown timber to be utilised in greater quantity in the construction industry, a more radical and innovative approach must be considered. The development of homegrown timber based construction products in the form of engineered and prefabricated timber components could offer a strong and valuable market for homegrown resources, which would enable sustainable growth and investment throughout the forest and timber industries.

A review of international precedents has identified a number of opportunities for the development of an innovative method of construction specifically focused on enabling self build. Timber construction in the UK is dominated by imported timber based panel systems, however there are a number of radically innovative timber construction systems available within the UK. These systems often employ alternative approaches to the structural arrangement of a timber based construction system. An analysis of the primary structural types would suggest that there is great opportunity for simplifying the construction process and the performance demands placed on homegrown timber components, if arranged in a modern post and beam frame type structure. This review has also provided a useful indication of the potential barriers and limitations that must be overcome in order for a MMC system to be successfully adopted by the construction industry.

It can be summarised therefore that for a Modern Method of Construction using homegrown timber to be appropriate and viable for the construction of affordable housing in rural Wales, including the use of self build methods, it must;

- be appropriate to the resource, ie make use of readily available standard sections of homegrown timber without the need to significantly reprocess.
- be tailored to the physical and mechanical properties of the resource, most critically, to stabilise the timber against distortion.
- be flexible and enable a high standard of quality in design and specification to meet the expectations of the marketplace throughout the building's life.
- be at least competitive in capital and whole life costs with the existing house building industry.
- make use of the existing resources of the timber and construction industries, including facilities, machinery and skills in order to minimise the potentially high capital investment costs associated with MMC.
- be proportionate in scale, complexity and manufacturing capacity to the context of affordable housing in rural Wales, where a need in the region of 2500 units per annum has been identified.

Chapter 4.0

Methodology

4.01 INTRODUCTION

In Chapter 1.0, a set of research objectives were introduced. In Chapters 2.0 and 3.0, a literature and observational study have informed these objectives and found that;

- Homegrown Welsh softwood, principally Sitka Spruce, is available in a range of dimensions in high quantities from sustainably managed, harvested and processed supply chains. It is currently used for a range of low value applications.
- There are significant barriers to its substitution for imported timber in the existing timber frame construction industry. This results in the need for a radical and innovative approach to be taken in order for the construction industry to reassess the value of homegrown timber in construction.
- The provision of affordable housing for rural Wales is an acute challenge that must consider alternative methods of delivery to overcome significant barriers in the existing house building industry.
- Through the extension of existing planning policies, self build construction could offer great potential as an alternative delivery mechanism, independent of commercially driven volume housebuilders. This could offer positive social benefits through use of local skills and resources in addition to the physical delivery of affordable housing units.

4.02 HYPOTHESIS

Homegrown softwoods can be re-engineered using low technology and low intensity manufacturing processes to provide a self build affordable rural housing solution.



Figure 4.1: Proposed research programme showing key delivery components alongside the research programmes of Elements Europe Modular and the Sitka Spruce Housing research project.

4.03 METHODOLOGY

The following investigation will employ design based research to prototype, test, develop and inform this working hypothesis and meet identified research objectives.

The investigation will begin with an analysis of national housing standards and the housing market in order to propose a performance specification for sustainable, affordable housing, against which design studies will be tested.

Three stages of preliminary design studies will then be performed;

- Prototype testing and development of homegrown timber components
- Design Pattern Book of House Types
- Prototypical Construction Studies

These stages of development will consider a matrix of research outcomes set out in the form of a development framework, shown in Table 4.1. Outcomes are categorised against the proposed Performance Specification, and designed to inform the development process. This will result in a set of final test parameters which will be examined through the construction of a prototype unit.

Figure 4.1 shows the approximate time line for this research study and its relationship with the broad Ty Unnos development project.

4.03.1 PERFORMANCE SPECIFICATION

The first stage of the investigation will be the identification of a performance specification. In conjunction with the research objectives, this will set a benchmark against which a proposed system of homegrown timber components can be tested for appropriateness for as an affordable housing solution. This will take the form of a literature review and precedent study, considering national standards and the demands of the market place to establish standards for environmental performance, design, quality and space standards, and economic profile.

4.03.2 PROTOTYPE TESTING AND DEVELOPMENT

Chapter 6.0 Component Prototyping and Testing takes the form of a narrative of the component development process, summarising the design, development and testing procedures applied to the proposed engineered timber components. The testing process has been led by Burroughs with prototyping provided by Coed Cymru. The study will, in most part, record this process and the decision making that has determined its development. However, significant original contributions of this study include; the development of a target specification for homegrown timber components, and the design and development of prototypes.

This study will culminate in a resolved matrix of homegrown timber components available for construction applications with associated performance criteria.

4.03.3 DESIGN PATTERN BOOK

In Chapter 7.0 Design Pattern Book, design studies will investigate the organisation of a construction system based on parameters such as design flexibility, space standards and manufacturing and construction efficiencies. This will firstly consider the organisation of room types, and then be applied to whole house scenarios and a rural development site. This process will inform the design and detailing of construction components, specifically in the form of component geometry and target structural capacities. It will also explore the design implications of using prefabricated systems to deliver affordable housing in the diverse context of rural Wales.

4.03.4 PROTOTYPICAL STUDIES

Following a period of sustained publicising, the Ty Unnos project has yielded a number of exciting opportunities to test home grown timber components through the construction of commercial projects. The Project Team led by the Design Research Unit Wales and Coed Cymru has therefore identified a number of key projects to assist in the development of the System. These projects will test parameters such as build ability, economic and environmental performance, design and performance in use. Projects will employ home grown timber components in various stages of development, in order to test, develop and refine components for application.

Chapter 8.0 Building Studies will summarise four construction projects completed during the research period by the Project Team, and provide an overview of the key findings from each project. Contributions of this study to these projects have varied from initial design development through to detailed design and generation of production information. In each project however, each stage of design and construction has been monitored and interrogated against proposed research outcomes.

4.03.5 PROTOTYPE UNIT

The conclusion of these preliminary design based studies will involve the design, manufacture and construction of a full scale construction prototype. Proposed as a small and temporary unit on the site of the Coed Cymru head office, the Rural Studio will endeavour to provide a complete structural and thermal envelope to meet the proposed performance specification and suggests detailing and componentry which can be scaled to full scale house constructions. The studio will be manufactured and constructed using the limited manufacturing and construction skills of myself and a number of helpers, and the machinery and facilities of a standard prototyping workshop. This mirrors the level of low technology manufacturing and self build that may be anticipated in the context of self build rural housing.

PERFORMANCE CRITERIA	STANDARD	COMPONENT TESTING + DEVELOPMENT	DESIGN PATTERN BOOK	PROTOTYPICAL STUDIES			
				LLANDEGLA FOREST VISITOR CENTRE, COED LLANDEGLA	ENVIRONMENTAL RESOURCE CENTRE, EBBW VALE	WELSH PAVILION, SMITHSONIAN FOLKLIFE FESTIVAL	WELSH PASSIVE HOUSE, EBBW VALE
COMPONENT DESIGN AND CERTIFICATION							
STRUCTURAL ORGANISATION	Portalised Structure						
	Post and Beam Frame						
	Single Storey						
	Multi Storey						
COMPONENT PERFORMANCE	Box Section Frame						
	Threaded Rod Connector						
	Solid Section Connector						
	Ladder 1 _ Solid Flange						
	Ladder 2_ Nail Laminate						
BUILDING DESIGN							
SPACE AND QUALITY	Space Standards						
	Lifetime Homes						
DESIGN FLEXIBILITY	Form						
	Scale						
	Organisation						
	Materials						
	Openings						
‘DELIGHT”							
DETAILED DESIGN							
CONSTRUCTION ELEMENTS	Sub Structure			CONCRETE PILE	TRENCH FOOTINGS		GROUND BEARING RAFT
	Structure - Primary			PORTAL FRAME	PORTAL FRAME		POST + BEAM 2 STOREY
	Structure - Secondary					LADDER BASED PANEL	SOLID STUD INFILL
	Thermal Envelope				SIPS INFILL PANELS		BLOWN WARMCEL
	Services						
DIMENSIONAL COORDINATION	Organisation						
	Scale & Weight of Components						
	Standardisation						
WARRANTY & NATIONAL STANDARDS	Planning Approvals						
	Building Regulations						
	National House Building Council						
ENVIRONMENTAL PERFORMANCE	Thermal Performance						
	Airtightness						
	Code for Sustainable Homes						
	PassivHaus						
MANUFACTURE							
ASSEMBLY METHOD	Low Technology Assembly						
	Semi- Automised						
	High Craft / Bespoke Assembly						
SUPPLY CHAIN							
CONSTRUCTION / BUILDABILITY							
CONSTRUCTION SKILL TYPE	Low Skill / Self Build						
	High Skill / Specialist						
	'General" Contractor						
REFLECTION							
ECONOMIC PROFILE							
OCCUPATION RESPONSE							

Table 4.1: Development Framework of proposed research outcomes.

4.04 SCOPE AND LIMITATIONS

The scope of this research has been significantly extended by the opportunity to contribute to and reflect upon the ongoing research of the Project Team. Due to the limitations of funding it would not be possible to achieve these research objectives otherwise. Consequently the methods and data analysed are not unique to this study. However the interpretation and reflection of research findings will be exclusive to the specific objectives identified for this research study.

It is proposed that this research method will provide a comprehensive evaluation of the development process embarked upon by the Project Team in the development of homegrown timber components for construction. By design, prototyping and construction, these findings will then be applied to the specific application of a self build solution for affordable rural housing.

Limitations posed by this method of data collection include;

- A limited ability to reflect upon commercially identified findings, for example, economic performance of homegrown timber components will be informed during the construction of prototypical studies and may therefore be limited in its general usefulness due to the bespoke nature of these studies and the current structure of the supply chain.
- As development routes and testing proposals, specifically in the design and manufacture of construction components, will be determined by the wider Project Team, formal testing may not always accurately reflect design intentions directly appropriate to the objectives of this study.
- The research study is necessarily limited in scope, therefore it is unlikely to be within the scope of this study to consider the long term application of homegrown timber construction components and its delivery to market.
- Investigations into manufacturing viability and efficiency, specifically in regards to economies of scale, manufacturing capacity, material efficiency, product rejection and appropriateness of manufacturing methods to existing industries, are likely to be limited to the resources available to the members of the Project Team, and their commercial motivations.

Chapter 5.0

Performance Requirements for Affordable Housing

a study of national and international standards in the identification of a performance
specification for affordable housing

5.01 INTRODUCTION

In this chapter, a consideration of literature and best practice precedents will inform the generation of a performance specification based on obligatory and optional standards. This will be considered under 5 headings;

- Testing and Certification
- Construction Standards
- Space and Quality Standards
- Thermal Performance
- Economic Profile

The findings will be tabulated as a detailed performance specification against which a proposed system of homegrown timber components can be tested for appropriateness for affordable rural housing. Figure 5.1 describes the research methodology designed to apply and test the proposed construction system against each element of the performance specification.

The public house building sector demands perhaps the highest performance standards of construction in the UK. In addition to meeting the improving standards of National Building Regulations, Affordable Housing must offer a higher standard of performance in order to fulfil the strict criteria set for public funding. This includes environmental and sustainable performance, space and quality standards and financial profiles. As a result, affordable housing is often utilised as a showcase for the construction industry as a whole, theoretically striving for and demonstrating best practice in the industry. A example of this is the Design for Manufacture competition or £60k House, launched by The English Partnerships in 2005 to stimulate the construction industry and assist in building a case for MMC as a replicable, cost effective and quality solution to house construction.

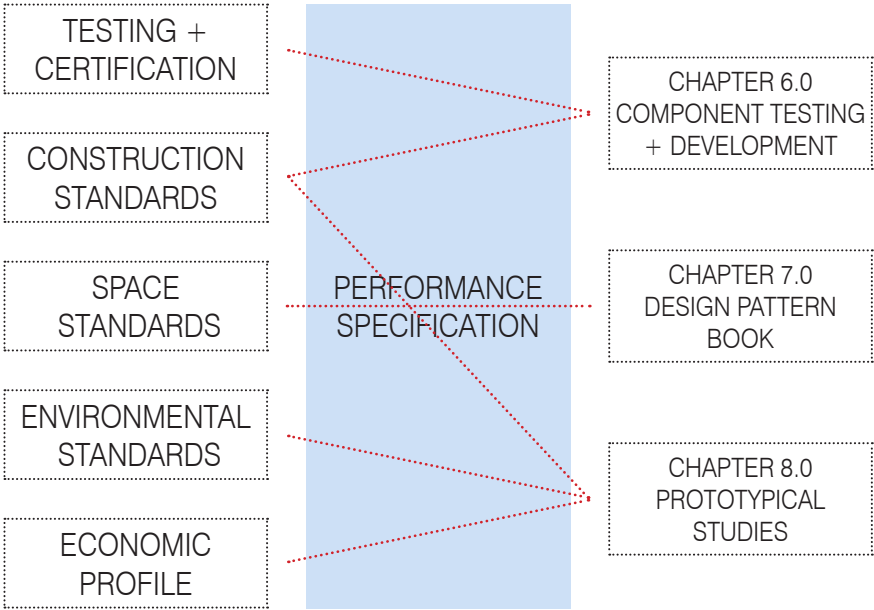


Figure 5.1: Matrix of standards to be tested through design studies.

The first element of the research methodology is the prototyping, testing and development of homegrown timber components for use as structural construction components. A review of national and international requirements for structural performance and construction product certification will provide context for this process in order to establish the standard against which construction components can be considered fit for purpose.

In the context of house construction, the marketplace demands that new build homes are offered with appropriate warranties, protecting the homeowner and mortgage provider against construction defects. In order to minimise risk and ensure good practice, warranty providers such as the National House Building Council have established stringent quality and performance specifications in the form of published construction standards. A study of these standards will inform the development of components and be tested through the construction of Prototypical Studies, discussed in Chapter 6.0 and Chapter 8.0 respectively.

A study of national space and quality standards will then establish a minimum target specification for the generation of a Design Pattern Book in Chapter 7.0. Affordable housing in the UK is specified to ensure high quality and space standards are adhered to throughout the publicly funded construction sector. The WAG have until recently, published the Design Quality Requirements, which incorporate the Lifetime Homes requirements, as a minimum standard for publicly funded Affordable Housing in Wales. The publication of the London Housing Design Guide has however proposed an alternative direction for housing standards in the UK. Although not currently applied generally, it suggests an appropriate assessment of the future demands of the sector.

Over the past decade, environmental and sustainable performance has become dramatically more demanding in order to meet the governments' climate change agenda. The current mechanism employed by the WAG, the Code for Sustainable Homes, is described as a step change sustainability tool in order to meet a target of Zero Carbon construction in Wales by 2016. Although performance targets typically cover a broad range of sustainability criteria, an analysis of current and proposed environmental standards will focus primarily on the specification of a thermal fabric. This will be tested for appropriateness and buildability, initially through the construction of prototypical studies, analysed in Chapter 8.0.

The construction of prototypical studies will also provide opportunity to investigate the economic profile of the proposed homegrown timber construction system. A brief analysis of precedents and Acceptable Cost Guidance published by the WAG will identify a target cost range, tailored specifically to the context of affordable rural housing for Wales and the proposed performance specification.

5.02 TESTING AND CERTIFICATION

The objectives of this and the broader Ty Unnos research project propose the development of universally applicable construction products, which can be employed freely across the industry in a variety of forms and scales. The prototypical studies performed as part of this research project will be carried out as bespoke construction applications. However in order for a system of homegrown timber components to successfully fulfil the research objectives it must be appropriate to the scale and volume of affordable housing need in rural Wales. A system must therefore be applicable to multiple sites and development types, and be available for use by architects, consultants and clients.

It is therefore intended that the formal testing of homegrown timber components will enable the formation of a comprehensive source of component performance information which can be applied to the structural design of buildings without the need to retest or place additional demand on consultants.

In order to meet this objective, the outcome of prototyping, testing and development must be considered as a 'construction product'. This could be at the scale of individual components, in a similar manner to a product such as JJI joists, or as a whole house construction solution.

5.02.1 THE CONSTRUCTION PRODUCTS DIRECTIVE

The Construction Products Directive (CPD) 1988 is designed to ensure that construction products produced within the European Union can be appropriate for construction applications in any of the member states. In order for this freedom of movement, it has been necessary to harmonise national laws and standards to ensure products are designed to standardised specifications. This process of standardisation has resulted in two forms of technical specification for construction products;

- A harmonised set of European Standards developed and adopted by the European Committee for Standardisation, CEN
- And a system of European Technical Approvals (ETAs) to assess the suitability of a product for its intended use where there are no harmonised standards.

The Directive requires that products, which are incorporated into constructions, are adequate to ensure the construction as a whole performs under six essential criteria;¹

- Mechanical resistance and stability
- Safety in case of fire

1 BM TRADA, *CE Marking for the CPD* (High Wycombe: TRADA)
<<http://www.bmtrada.com/cemark.php#ER>> [accessed 10 Jun 2012]

- Hygiene, health and environment
- Safety in use
- Protection against noise
- Energy economy including heat retention

In order for a product to comply with the directive and subsequently bear a CE marking, it must either be designed and manufactured in compliance with the Harmonised European Standard or in the absence of an appropriate standard, be considered compliant through the European Technical Approval process.²

5.02.2 HARMONISED EUROPEAN STANDARDS- EUROCODES

The Eurocodes are a set of harmonised structural design codes for building and civil engineering works developed by the European Committee for Standardisation, CEN. They are considered mandatory for all European Public works and it is intended that they will become the standard for the private sector worldwide. They have replaced existing British Standards for the assessment of national Building Regulations and are the framework for assessing compliance for CE marking.

The Codes were published in all main European languages between 2002 and 2007 and existed alongside national standards until the 31st March 2010 when the existing national standards were planned for withdrawal.

The Codes are published under 10 headings covering individual structural materials and factors such as geotechnical and seismic aspects of structural design. BS EN 1995-1 Eurocode 5: Design of Timber Structures has now replaced BS 5268 Structural Use of Timber, and applies to the design of buildings using timber including solid timber, glue laminated timber, wood based structural products and wood based panel products.

TRADA advise that the main difference between BS 5268 and EC5 is the approach to design whereby a 'Limit State' design philosophy is applied. This philosophy is shared throughout the Eurocodes allowing for designers to move much more easily between the design of timber structures, to steel and concrete. This replaces BS 5268, where a 'Permissible Stress' approach to design is employed, calculated predominantly from tabulated values with built in safety and duration factors.

The Eurocode structure theoretically enables a more accurate calculation system and enables much greater continuity and consistency throughout. Specifically, as safety and durability factors are applied formulaically they can be tailored and modified to suit specific applications.

2 EOTA, *What is an ETA?* (Brussels: EOTA)
<<http://www.eota.be/en-GB/content/what-is-an-eta/4/>> [accessed 10 Jun 2012]

5.02.3 EUROPEAN TECHNICAL APPROVALS

In addition to the Eurocode system, the Construction Products Directive has facilitated the introduction of a system of European Technical Approvals, ETAs. Under the Directive a product is deemed fit for their intended use and subsequently may bear a CE marking if a valid ETA is attained and an associated Attestation of Conformity procedure is in place. In most cases an ETA will be granted for a product based on assessment principles set out in a product specific ETA Guideline (ETAG). When an ETA has been issued it is typically valid for a period of five years, and is applicable in all European Economic Area countries.³

ETAs are most relevant for innovative or new products which are not directly covered by Harmonised European Standards. Where assessments have been completed on a series of similar products of product types, procedures for assessment and testing have been developed and formalised into European Techncial Assessments Guidelines, ETAGs. The European Organisation for Technical Approvals (EOTA) is the approval body responsible for coordinating the issue of ETAs and monitoring the drafting and publication of ETA Guidelines.

The basic aim of the ETAGs is to set out the procedure that nominated Approval Bodies must follow when assessing the specific requirements and characteristics of a product or family of products. The guidelines therefore comprise;⁴

- A list of relevant Interpretative Documents
- The specific requirements for products as established by the Essential Requirements
- All necessary test procedures
- Methods for assessing and judging the results of testing
- Procedures related to the Attestation of Conformity
- And the period of validity of the approval.

5.02.4 ETAG 007 TIMBER BUILDING KITS

ETAG 007 is prepared by the EOTA as a guideline for the assessment of “*industrially prepared kits, marketed as a building, that are made of pre-designed and prefabricated components intended for production in series*”⁵

The guideline covers the spectrum of prefabrication from pre-cut timbers assembled on site to factory finished building sections. Under this assessment procedure however, the CE marking is only applied to the final completed building

3 Ibid.,
4 EOTA, *What is an ETAG?* (Brussels: EOTA) <<http://www.eota.be/en-GB/content/what-is-an-etag/7/>> [accessed 10 Jun 2012]
5 European Organisation for Technical Approvals, *ETAG 007 : Guideline For European Technical Approval Of Timber Frame Building Kits* (Brussels: European Organisation for Technical Approvals, 2001), p. 5.

and cannot be applied to individual components of the system.⁶

In order for a kit to be appropriate for assessment it must contain all components required to satisfactorily fulfil the Essential Requirements described above. Typically this includes;⁷

- Structural elements including walls, floors, roof structures and their connections including connections to substructure.
- The Building Fabric, including thermal insulation, internal linings, fire protection, vapour control, waterproofing such as masonry claddings, and windows and doors
- Internal walls including soundproofing, linings and fire protection
- Preparation for services.

The guidelines are laid out in three main chapters. Firstly, the 6 Essential Requirements as set out previously, are detailed specifically in relation to the design of timber frame building kits. Two chapters, Methods of Verification, and Assessing and Judging the Fitness of Use then describe the procedures required to ensure the system is assessed appropriately against each of the criteria. This includes identifying key standards, typically within the Eurocodes, and outlining specific performance calculations required to ensure compliance. The majority of these assessments fall within the common assessment practices required by Building Regulations.

ETAG 007 is based upon an assumed working life of 50 years for the main structural elements of the system. A lower life expectancy of 25 years is set for repairable or replaceable elements such as cladding, windows and doors. However the maintenance and repair requirements associated with the proposed system must be specified in the assessment procedure. ETAG 007 also establishes mechanisms for quality control. In addition to the controls of manufacture set out by the Attestation of Conformity, a manual for installation, transportation and storage of the kit is required for assessment by the approval body to ensure that all site works are completed to the requirements as set out in the ETA.

5.02.4 ATTESTATION OF CONFORMITY

In order for a product to comply with an ETA and subsequently receive a CE mark it must have an associated Attestation of Conformity. The method of the AoC is dependent on the product type and particularly the level of safety criticality that a product may hold. The Attestation of Conformity has 6 levels of requirements with 1 + being the highest and 4 being the lowest.⁸ At the lowest levels a manufacturer’s

6 Ibid., p. 5.
7 Ibid., p. 9.
8 British Board of Agreement, *Attestation of Conformity* (Watford: BBA) <<http://www.bbacerts.co.uk/ce-marking/attestation-of-conformity.aspx>> [accessed 11th May 2012]

declaration is sufficient without any third party assessment.

All products designed to ETAG 007 are considered as highly critical to safety and therefore require assessment to Attestation of Conformity system 1.⁹ This includes;

1. Production control
2. Audit testing according to a prescribed test plan.
3. Initial type testing
4. Initial inspection of factory and production control
5. Surveillance of factory production control
6. Product certificate

Items 1 and 2 of these requirements are to be performed by the manufacturer, however all other items must be performed by an Approved Body.

5.02.5 APPROVED BODIES

The EOTA recognise seven organisations in the UK as Approved Bodies for the assessment and issuing of ETAs.¹⁰ Of the seven Approved Bodies, three have approval to issue ETAs designed specifically to ETAG 007;

- British Board of Agreement
- Building Research Establishment Global Ltd
- BM TRADA Certification Ltd

For the purpose of this study and the broader Ty Unnos research project, following guidance from Burroughs and TRADA, it has been established that the ETAG 007 process should be the target development route in order to achieve the objectives of the project.

9 European Organisation for Technical Approvals, *ETAG 007 Guideline For European Technical Approval Of Timber Frame Building Kits*, p 37.

10 EOTA, *EOTA Member List* (Brussels: EOTA), <<http://www.eota.be/en-GB/content/eota-member-list/42/33/>> [accessed 11th May 2012]

5.03 CONSTRUCTION STANDARDS

The context of affordable housing can often place additional demand on the standard of construction, beyond those required to meet national Building Regulations. Whether provided publicly or privately, the domestic market demands the ability to finance and insure properties.

In most cases these facilities are reliant on service providers ensuring confidence in construction standards. The most common system in the UK housing industry is to provide protection in the form a building warranty, and the most popular form of warranty for housing is provided by the National House Building Council.

5.03.1 NATIONAL HOUSE BUILDING COUNCIL

The National House Building Council is the leading warranty and house building provider for new and newly converted homes in the UK. They provide warranty cover for approximately 80% of new homes built in the UK including social housing developments provided by Registered Social Landlords and Housing Associations and have an approved register of approximately 18,000 house builders and developers.

The association was created in 1936 as the National House Builders Registration Council as a voluntary registration scheme which allowed approved builders, building to a standard construction specification, to offer a 2 year warranty against major defects to the property and provide cover in the case of insolvency. In 1965 this became a 10 year warranty now known as the Buildmark Warranty. By 1973, members of the renamed National House Building Council were responsible for the construction of 92% of the new homes built in the UK.

In order to ensure calculated risk the Council established a set of standards to which all registered builders must adhere to for the warranty cover to apply. These standards build on the standard Building Regulations and focus on ensuring quality and robustness to minimise risks. The Council promotes itself as a leading standard for housing not just to ensure construction standards but to ensure the provision of high quality housing for homeowners.

5.03.2 BUILDMARK WARRANTY

The NHBC provide two main types of warranty cover for domestic construction;

- Buildmark is the market leading warranty for new and newly converted private sector housing,
- Buildmark Choice is a warranty and insurance cover designed to protect Registered Providers, tenants and shared owners of affordable housing. It covers over 80% of the UK’s social housing developments provided by Registered Social Landlords and Housing Associations.

Both forms of warranty employ a three stage system of cover; a pre completion insolvency cover, a post completion contractor liability period of two years, and finally a period of damage cover extending to a total of 10 or 12 years warranty and insurance cover.¹¹

In order for builders and developers to offer homes with a product from the NHBC Buildmark warranty range they must first complete registration for the approved NHBC Register. This requires the successful completion of a Commercial Assessment and a Technical Assessment which will review construction standards, site management and health and safety procedures. Assessment is typically performed on a minimum of one new build home, with onsite assessments performed throughout the construction process.¹² The completion of registration for Builders also includes an introduction to the NHBC Technical Standards.

5.03.3 NHBC STANDARDS

The NHBC Standards set out the minimum technical requirements for the design and construction of dwellings to be deemed acceptable to receive cover from one of the NHBCs range of warranty and insurance cover. The Standards are reviewed regularly, with the current applied NHBC Standard 2011 coming into effect for all registered homes whose foundations are concreted on or after 1 January 2011.

A Standards Committee comprising a range of interest groups, including professional institutions, house builders, the Housing Corporation and the Office of the Deputy Prime Minister, manage the content of the Standards.

The NHBC Standards are set out in three forms;¹³

- Technical Requirements are mandatory requirements which must be met by the builder, illustrated in red,
- Performance Standards are set out in black and give detailed standards of performance for each Design, Materials or Sitework section. The NHBC will only consider alternative standards if the Technical Requirements are met and the standard is not lower than the stated Performance Standard,
- Guidance is printed in blue and illustrates the normal construction procedures and recommended practices that have been found to satisfactorily meet the Performance Standard.

11 NHBC, *Why choose Buildmark Choice for affordable housing?* (Milton Keynes: NHBC), <<http://www.nhbc.co.uk/Warrantiesandcover/Buildersanddevelopers/Affordablehousing-BuildmarkChoice/>> [accessed 11th May 2012]

12 NHBC, *Frequently Asked Questions* (Milton Keynes: NHBC), <<http://www.nhbc.co.uk/Builders/Builderregistration/BecomingNHBCregistered/FAQs/>> [accessed 11th May 2012]

13 NHBC, *NHBC Standards 2010: Part 1 General Information* (Milton Keynes: NHBC, 2010), p1.

*“NHBC will consider alternative methods to meet specific requirements, subject to prior consultation and evaluation”*¹⁴

The mandatory Technical Requirements are set out in Chapter 1.1 of the NHBC Standards and take the form of 5 short statements;¹⁵

- R1 Statutory Requirements - Work shall comply with all relevant Building Regulations and other statutory requirements relating to the completed construction work
- R2 Design Requirement - Design and specification shall provide satisfactory performance
- R3 Materials Requirement - All materials, products and building systems shall be suitable for their intended purpose
- R4 Workmanship Requirement - All work shall be carried out in a proper, neat and workmanlike manner
- R5 Structural Design Requirement - Structural design shall be carried out by suitably qualified persons in accordance with British Standards and Codes of Practice

Although all of the Technical Requirements are mandatory, Requirements R3 and R5 would seem to be most critical to the design and specification of an innovative construction system. In order to meet Requirement 3, the Standards advise that materials and products may be considered acceptable for critical functions such as Structure if designed in accordance with standards set out by the NHBC. In the scenario where a product or material does not comply with the NHBC Standard or relevant British Standard, it is suggested in R3(a)(iv) that assessment by an appropriate independent technical approvals authority such as the British Board of Agreement or the Building Research Establishment, would be considered acceptable for compliance.¹⁶ This is further referenced in item R3(d) Proprietary Building Systems.

Requirement R5 states that any structural element, which is not based on specific design criteria as established by the NHBS Standards, or any dwelling which is not constructed in accordance with traditional UK practice should be designed by a Chartered Civil or Structural Engineer.¹⁷

The Standards are composed of 10 parts, each covering a particular aspect of construction, however sections 2.3 Timber Preservation (Natural Solid Timber) and 6.2 External Timber Framed Walls would appear to contain the most relevant criteria for the design of an innovative timber construction system.

14 Ibid., p1.
15 NHBC, *NHBC Standards 2010: Part 1 General Information* (Milton Keynes: NHBC, 2010), p2-3.
16 Ibid., p2.
17 Ibid., p3.

Section 6.2 External Timber Framed Walls of the NHBC Standards is based predominantly on the design of open or closed timber frame panel systems, typically in conjunction with an outer leaf of brickwork/ masonry cladding and ground bearing concrete slab. Perhaps the most defining criteria in Section 6.2 is the requirement for the lowest structural timber to be a minimum of 150mm higher than ground level.¹⁸ This was revised in 2008 to permit this to be reduced to 75mm in exceptional circumstances.¹⁹ Where timber with a moderate or lower durability rating is specified such as homegrown softwoods, it is advised that a preservative treatment is applied for the majority of tasks including sole plates, external walls, roof timbers, and I joists. Acceptable preservative treatments include copper organic compounds, organic solvents or microemulsion and boron.²⁰

5.03.4 ALTERNATIVE WARRANTY PROVIDERS

Up until September 2009 Zurich Building Guarantee was considered to be one of the leading new build warranty providers in the UK. The most popular of its products “Standard 10” provides cover for private sale new build homes. As with most of the alternative warranty providers, the cover is very similar in form to the NHBC Buildmark cover offering; insolvency cover, a developer’s warranty period and a 10 year structural insurance period. As with the NHBC, Zurich publish a Technical Manual to which all properties must be designed and constructed. In 2009 Zurich ceased to offer warranty and insurance cover in the UK due to the sustained decline of the UK housing market.²¹

Other providers of new home warranties in the UK include;

- Building LifePlans Secure
- Local Authority Building Control New Home Warranty
- Premier Guarantee.
- Build-Zone Structural Warranty

18 NHBC, 'Chapter 6.2 External Timber Frame Walls', *NHBC Standards 2010* (Milton Keynes: NHBC, 2010), p2.

19 NHBC, *NHBC Standards Extra May 2008* (Milton Keynes: NHBC, 2008), p3.

20 NHBC, 'Chapter 2.3 Timber Preservation (Natural Solid Timber)', *NHBC Standards 2010* (Milton Keynes: NHBC, 2010), p3.

21 Daniel Dunkley, *Zurich To Exit New-Home Warranty and Building Control Markets* (London: Post Online, 2009), <<http://www.postonline.co.uk/post/news/1556918/zurich-exit-home-warranty-building-control-markets>> [accessed 11th May 2012].

5.04 SPACE + QUALITY STANDARDS

5.04.1 WELSH HOUSING QUALITY STANDARDS

The Welsh Housing Quality Standard was introduced in 2001 in order to facilitate the Welsh Assembly's objective that,
*“All households in Wales should have the opportunity to live in a good quality home within a safe and secure community”.*²²

The Welsh Assembly have set a requirement for all existing stock to be brought up to the WHQS by the end of 2012. The standards ensure that homes are;

- In a good state of repair
- Safe and secure
- Adequately heated, fuel efficient and well insulated
- Contain up to date kitchens and bathrooms
- Well managed (for rented housing)
- Located in attractive and safe environments
- As far as possible suit the specific requirements of the household (eg specific disabilities)²³

The WHQS July 2008 details the current minimum standards against each of the categories detailed above including minimum space standards. It is assumed that all new dwellings built to the Design Quality Requirements will meet and surpass the standards set by WAG through the WHQS. However the WHQS is a monitoring standard for affordable housing and all new housing should ensure that they are maintained, updated and managed to ensure continued compliance with quality standards.

5.04.2 DEVELOPMENT QUALITY REQUIREMENTS

*‘The dwellings provided by housing associations should be of good quality and suitable for the needs of the intended tenants’*²⁴

The WAG’s Design Quality Requirements (DQR) set out guidance for Housing Associations and Registered Social Landlords to ensure good practice and protect public investment in affordable housing.²⁵ All housing acquired or developed by HAs are required to meet minimum requirements identified in the DQR.²⁶ The

22 Welsh Assembly Government, *Social Housing* (Cardiff: WAG), <<http://wales.gov.uk/topics/housingandcommunity/housing/social/?lang=en>> [accessed 11th May 2012].

23 Housemark Cymru, *The Welsh Housing Quality Standard: Revised Guidance for Social Landlords on Interpretation and Achievement of the Welsh Housing Quality Standard* (Cardiff: WAG, 2008), p2.

24 Welsh Assembly Government, *Design Quality Requirements: Design Standards and Guidance* (Cardiff: WAG, 2005), p2.

25 Ibid., p2.

26 Ibid., p3.

DQR are suggested as a minimum standard for new build housing, but to ensure continued flexibility and adaptability as the needs of the users change, the DQR adopt requirements set out in the Joseph Rowntree Foundation's Lifetime Homes.²⁷ Lifetime Homes are a set of 16 requirements with the common theme of increased accessibility and adaptability with particular focus on the ability to adapt to a member of the household suffering from reduced mobility.²⁸ As well as being mandatory under the DQR, the Lifetime Homes Standard is now fully integrated into the Code for Sustainable homes and is a mandatory requirement for those seeking CSH Level 6.

The DQR were last revised in 2005 to include improved standards of accessibility for people with disabilities, enhanced security, improved levels of sustainable construction and integration of the Lifetime Homes criteria. The 2005 DQR require that all general needs schemes and housing for the elderly must be built to achieve a BRE Ecohomes rating level of 'Good'.²⁹ Ecohomes is a credit based rating system with credits awarded for site specific sustainability criteria including public transport, ecology and flood risk and sustainable design and construction factors. The Ecohomes assessment was replaced in England, Wales and Northern Ireland in 2007 by the Code for Sustainable Homes however DQR has yet to be revised to this standard.

5.04.3 DESIGN PATTERN BOOK

The DQR are provided alongside a Pattern Book of flats, bungalows and houses. The Pattern Book was developed in 1993 through collaboration with tenants, HAs, designers and developers. Since its issue the range of housing has developed and evolved to respond to feedback and changing legislation regarding housing standards.³⁰ The Pattern Book is intended to rationalise house design to aid the delivery of cost effective and good quality publicly funded housing however it is supported by statements that suggest the Pattern Book is an attempt to guide rather than dictate a standardised housing form, construction type or architectural style.

House types are developed as formal internal arrangements with suggested furniture, door and window arrangements and minimum gross floor areas. It is intended however that these layouts are regarded as suggestions of relationships between elements rather than prescriptive fixed positions. Elements such as windows and doors can therefore be altered to suit the designer's elevational treatment and site context as long as it can be shown that the arrangement

27 Ibid.,, p7.
28 Ibid., p29.
29 Ibid., p15.
30 Ibid., p27.

	The Lifetime Homes Standards	
1	Car Parking	Where car parking is adjacent to the home, it should be capable of enlargement to attain 3.3m width.
2	Access from Car Parking	The distance from the car parking space to the home should be kept to a minimum and should be level or gently sloping.
3	Approach	The approach to all entrances should be level or gently sloping.
4	External Entrances	All entrances should be illuminated, have level access over the threshold and have a covered main entrance.
5	Communal Stairs	Communal stairs should provide easy access and, where homes are reached by a lift, it should be fully accessible.
6	Doorways & Hallways	The width of internal doorways and hallways should conform to Part M, except that when the approach is not head on and the hallway width is 900mm, the clear opening width should be 900mm rather than 800mm. There should be 300mm nib or wall space to the side of the leading edge of the doors on entrance level.
7	Wheelchair Accessibility	There should be space for turning a wheelchair in dining areas and living rooms and adequate circulation space for wheelchairs elsewhere.
8	Living Room	The living room should be at entrance level.
9	Two or more storey requirements	In houses of two or more storeys, there should be space on the entrance level that could be used as a convenient bed space.
10	WC	In houses with three bedrooms or more there should be a wheelchair accessible toilet at entrance level with drainage provision enabling a shower to be fitted in the future. In houses with two bedrooms the downstairs toilet should conform at least to Part M.
11	Bathroom & WC Walls	Walls in the bathroom and WC should be capable of taking adaptations such as handrails.
12	Lift Capability	The design should incorporate provision for a future stair lift and a suitably identified space for a through the floor lift from the ground floor to the first floor, for example to a bedroom next to the bathroom.
13	Main Bedroom	The design and specification should provide a reasonable route for a potential hoist from a main bedroom to the bathroom.
14	Bathroom Layout	The bathroom should be designed for ease of access to the bath, WC & wash basin.
15	Window Specification	Living room window glazing should begin no higher than 800mm from the floor level and windows should be easy to open/operate.
16	Fixtures & Fittings	Switches, sockets, ventilation and service controls should be at a height usable by all (i.e. between 450 and 1200mm from the floor).

Table 5.1: The Lifetime Homes Design Criteria
Source: Lifetime Homes, *16 Design Criteria (up to 5 July 2010)* (London: Lifetime Homes, 2011), [http://www.lifetimehomes.org.uk/pages/design-criteria.html] <Accessed 14th May 2012>

provides a suitable response to furniture arrangement.³¹ The Pattern Book plans show critical internal dimensions only where it is key to maintaining a minimum standard, thus allowing complete flexibility over construction and material choices.

The WAG Pattern Book has now largely become negated. It is however common for HAs and RSLs to have their own Pattern books of house types and layouts, tailored to their own work practices, and agreed through consultation with the Housing Directorate and Planning Authorities.

5.04.4 LIFETIME HOMES

The concept of Lifetime Homes is to ‘make life as easy as possible for as long as possible because they are thoughtfully designed’

The Lifetime Homes specification is a set of 16 standards that are designed to provide accessible, adaptable and flexible accommodation for everyone including those with reduced mobility. The standards are not designed specifically for those with disabilities but they are designed to allow homes to be more flexible for all eventualities, and wheelchair accessibility was chosen as a suitable benchmark to achieve this.

The Lifetime Homes Standard is a minimum requirement for all public sector funded housing in Wales and Scotland, and will be required for all public sector housing in England with the introduction of new HCA standards in April 2011. It is also intended to become a requirement for all private sector housing by 2013.³² In order to achieve the standard, all 16 criteria must either be met or shown to be irrelevant for the development type.

Table 5.1 shows the 16 Lifetime Homes Standards.

5.04.5 HOUSING STANDARDS OUTSIDE WALES

The current standards applied to housing in England provided by the newly formed Housing and Communities Agency (HCA), were inherited from the merger between the English Partnerships and the Housing Corporation. The English Partnerships’ Quality Standards and the Housing Corporation’s ‘The Design and Quality Standards (D&QS)’ are therefore still applied to schemes constructed using public funding. The HCA initially proposed a timetable for the production of a new set of standards to combine the two schemes and remove conflicts, to be published in April 2010 however following a period of consultation the Housing Minister confirmed in November 2010 that the existing standards would be maintained for programmes directly funded by the HCA. This remains

31 Ibid., p28.
32 Department for Communities and Local Government, *Delivering Lifetime Homes, Lifetime Neighbourhoods: A National Strategy for Housing in an Ageing Society* (West Yorkshire: Communities and Local Government Publications, 2008), p13.

the case at time of writing.

The London Housing Design Guide (LHDG) was first published for consultation in July 2009, and has been applied to all housing built on London Development Agency land. It is proposed that the standards will start to be employed for schemes applying for funding from the London Homes and Communities Agency from April 2011.³³

The LHDG is described as a statement of intent by London Mayor Boris Johnson to ‘*the promotion of excellence in design quality and sustainability*’.³⁴ Although the guide is aimed at publicly funded projects in London the aim is to consolidate and simplify current regulations and requirements to influence good practice across the industry. It has been developed in conjunction and collaboration with the HCA and the timetable for delivery was proposed to run in parallel with the proposed HCA standards. Although specifically tailored to the unique challenges of the city of London, the Design Guide was intended to be fully compatible and reflective of the proposed HCA Standards.

The London Design Guide is the most recent publication to address space standards and is particularly useful in the development of a housing specification as it fully integrates Lifetime Homes requirements and Secured by Design into design standards. It is a useful comparison tool against the Welsh Assembly’s DQR, as it perhaps suggests an update to the occupier’s changing priorities and requirements.

In a similar manner to the Welsh DQR, space standards are derived from furniture requirements and access, including Lifetime Homes requirements, arranged by room type. The guide therefore suggests minimum room areas and overall floor areas based on occupancy levels without defining dwelling type.

33 Greater London Authority, *London Housing Design Guide* (London: Greater London Authority, 2010)
<<http://www.london.gov.uk/who-runs-london/mayor/publications/housing/london-housing-design-guide>> [accessed 11 May 2012]

34 Mayor of London, *London Housing Design Guide: Draft for Consultation 2009* (London: London Development Agency, 2009), p5.

5.05 THERMAL PERFORMANCE

5.05.1 BUILDING REGULATIONS

Approved Document Part L of the Building Regulations determines the minimum environmental performance requirement for all new buildings and alterations to existing buildings and establishes the calculation methods employed for their assessment. Part L1A of this document is specifically applied to new build dwellings. A revision of Part L of Building Regulations 2006 came into effect in October 2010.

Prior to 2006, Approved Document Part L assigned target U values to the key construction elements- wall, floor and roof, to act as a minimum standard for fabric performance. Building Regulations 2006 however introduced a new calculation process for determining minimum requirements for building fabric and energy use in the form of Target CO₂ Emission Rates (TER). This calculation system replaced previous requirements for Elemental and Target U Values. Calculated using the Government's Standard Assessment Procedure (SAP), TER are designed to allow much greater flexibility in the design of thermal envelopes whilst also taking in to account the energy required for heat, hot water, ventilation and fixed internal lighting, including low and zero carbon technologies.³⁵

In order to ensure that undesirable factors such as increased condensation levels does not become a risk due to poor fabric performance, Part L1A does however set out limiting values for individual fabric elements, these are shown in Table 5.2.³⁶

In order to identify a minimum or target specification for the thermal fabric of a construction system it is therefore no longer possible to simply determine target U Values.

5.05.2 CODE FOR SUSTAINABLE HOMES

The Code for Sustainable Homes was launched in December 2006 and became operational in April 2007 as part of a 10 year program of step changes to achieve the target of Zero Carbon house construction by 2016. The Code replaces the Building Research Establishment's Ecohomes System as the single national standard for England and Wales and is intended to inform the evolution of energy performance regulations as set out in Building Regulations Part L.

The Code employs a rating system of 1 to 6 'stars', with 1 star being the lowest standard of the Code set just above the requirements of Building Regulations 2006, and 6 stars being the highest standard, considered as 'Zero Carbon'.

Table 5.2: Limiting Fabric Requirements as set out in Approved Document L1A

Limiting Fabric Parameters	
Roof	0.2 W/m².k
Wall	0.3 W/m².k
Floor	0.25 W/m².k
Party Wall	0.2 W/m².k
Windows, roof windows, glazed rooflights, curtain walling and pedestrian doors	2.00 W/m².k
Air permeability	10.00 m³/h.m² at 50Pa

35 HM Government, *Building Regulations 2006: Part L1A Conservation of fuel and power in new dwellings* (London: NBS, 2006) Pp. 17-19.

36 HM Government, *Building Regulations 2010: Part L1A Conservation of fuel and power in new dwellings* (London: NBS, 2010) p.15.



Figure 5.2: Limiting Fabric Requirements as set out in Approved Document L1A
Source: Design Research Unit Wales, *Dwelling* (Cardiff: Low Carbon Research Institute, 2011), p. 2.

Based on the 2006 Building Regulations the Code sets minimum standards for water use and energy at each level of the Code. The majority of credits however are considered optional or tradable allowing for a flexible system of sustainable design particularly at the lower levels of the Code.

Since its introduction in April 2007, 18,339 post construction stage Code certificates have been issued up to December 2010. The majority, 90%, of these have been assigned a 3 star standard, and just 30 Code level 6 certificates have been issued by December 2010.³⁷

GOVERNMENT POLICY

The Code has been employed in England and Wales as a routemap for developing the performance requirements of all new housing to achieve the principle objective of Zero Carbon house construction by 2016.³⁸ In order to enforce this step change government policy has established mandatory Code based targets to be met first for all housing funded by public resources. Then, through changes to planning policy and Building Regulations, to all new dwellings built in England and Wales, see Figure 5.2.

With its One Wales agenda, the WAG specifically targeted the delivery of zero carbon construction by 2011 and has subsequently identified an increased delivery path.³⁹ Planning Policy Wales 2010, supplemented by TAN 22 Planning for Sustainable Buildings expects all new housing developments proposed after 11th December 2010, to meet Code Level 3 and achieve 6 additional credits for ENE1, equivalent to a 31% improvement over Building Regulations 2006. Following the transfer of Building Regulations powers on 31st December 2011, it is proposed that the first revised Building Regulations to be implemented in 2013 will set a requirement for a 55% improvement over the 2006 baseline.⁴⁰

ASSESSING THE CODE

Table 5.3 from the *NHBC The Code for Sustainable Homes Simply Explained*

37 Department for Communities and Local Government, *Code for Sustainable Homes and Energy Performance of Buildings: Cumulative and quarterly data up to December 2010* (West Yorkshire: Communities and Local Government Publications, 2011)
<<http://www.communities.gov.uk/publications/corporate/statistics/codesustainablesapq42010>> [accessed 14 May 2012]

38 Department for Communities and Local Government, *Code for Sustainable Homes: A step-change in sustainable home building practice* (West Yorkshire: Communities and Local Government Publications, 2006), p.5.

39 Welsh Assembly Government, *Written - Towards a Zero Carbon Future for Buildings in Wales* (Cardiff: Welsh Assembly Government, 2008)
<<http://wales.gov.uk/about/cabinet/cabinetstatements/2008/zerocarbon/?lang=en>> [accessed 14 May 2012]

40 Welsh Assembly Government, *Policy Statement - Welsh Assembly Government announces target for first changes to Welsh Building Regulations* (Cardiff: Welsh Assembly Government, 2010)
<<http://wales.gov.uk/topics/housingandcommunity/housing/publications/buildingregsstatement/?lang=en>> [accessed 14 May 2012]

Code for Sustainable Homes categories				
Category		Issue	Number of credits	Weighting factor (%)
1	Energy and CO ₂ emissions	Ene 1: DER (m)	29	36.4
		Ene 2: Building fabric		
		Ene 3: Internal lighting		
		Ene 4: Drying space		
		Ene 5: Energy-labelled white goods		
		Ene 6: External lighting		
		Ene 7: LZC technologies		
		Ene 8: Cycle storage		
		Ene 9: Home office		
2	Water	Wat 1: Indoor water use (m)	6	9.0
		Wat 2: External water use		
3	Materials	Mat 1: Environmental impact of materials (m)	24	7.2
		Mat 2: Responsible sourcing of materials – basic building elements		
		Mat 3: Responsible sourcing of materials – finishing elements		
4	Surface water run-off	Sur 1: Management of surface water run-off from developments (m)	4	2.2
		Sur 2: Flood risk		
5	Waste	Was 1: Storage of non-recyclable waste and recyclable household wastes (m)	7	6.4
		Was 2: Construction site waste management (m)		
		Was 3: Composting		
6	Pollution	Pol 1: Global warming potential of insulants	4	2.8
		Pol 2: NO _x emissions		
7	Health and well-being	Hea 1: Daylighting	12	14.0
		Hea 2: Sound insulation		
		Hea 3: Private space		
		Hea 4: Lifetime Homes (m at Level 6 only)		
8	Management	Man 1: Home user guide	9	10.0
		Man 2: Considerate Constructors Scheme		
		Man 3: Construction site impacts		
		Man 4: Security		
9	Ecology	Eco 1: Ecological value of site	9	12.0
		Eco 2: Ecological enhancement		
		Eco 3: Protection of ecological features		
		Eco 4: Change in ecological value of site		
		Eco 5: Building footprint		

Table 5.3: Code for Sustainable Homes Categories
Source: Christopher Gaze and others, *The Code for Sustainable Homes simply explained*, 2nd edn (Watford: IHS BRE Press, 2010), p. 3.

document describes the nine primary assessment categories. Each category and issue is assigned credits to be allocated against a number of mandatory and/or optional standards. These credits have weighted values as per there deemed importance, with Category 1- Energy and CO₂ containing the highest proportion of 36.4%, equating to 29 of 104 credits.

Table 5.4 describes the mandatory requirements established at Code 3 to 6. These mandatory credits are designed to establish minimum performance requirements throughout the Code range. Two issues are specifically identified;

- Ene 1: Energy
- Wat 1: Indoor Water Use

In both categories minimum standards are set at each code level in the form of percentage improvements of Dwelling Emission Rate (DER) over TER and Litres per Person per Day, respectively. In order to meet Code levels these requirements must be met.

Mandatory and optional scores for Code Levels 3–6												
	Code Level 3			Code Level 4			Code Level 5			Code Level 6		
	Mandatory requirements	Credits	Points	Mandatory requirements	Credits	Points	Mandatory requirements	Credits	Points	Mandatory requirements	Credits	Points
Ene 1: Energy	Percentage improvement of DER over TER: ≥25%	5	6.276	Percentage improvement of DER over TER: ≥44%	8	10.041	Percentage improvement of DER over TER: ≥100%	14	17.572	Zero carbon	15	18.828
Ene 2: Building fabric	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	HLP ≤0.8 W/m²K	2	2.510
Wat 1: Indoor water use	≤105 litres/ person/day	3	4.500	≤105 litres/ person/day	3	4.500	≤80 litres/ person/day	5	7.500	≤80 litres/ person/day	5	7.500
Mat 1: Materials specification	3 out of 5 elements to be A+ to D*	0	0	3 out of 5 elements to be A+ to D*	0	0	3 out of 5 elements to be A+ to D*	0	0	3 out of 5 elements to be A+ to D*	0	0
Sur 1: Surface water run-off	Peak run-off to not increase*	0	0	Peak run-off to not increase*	0	0	Peak run-off to not increase*	0	0	Peak run-off to not increase*	0	0
Was 1: Storage of non-recyclable waste and recyclable household waste	Space for household waste*	0	0	Space for household waste*	0	0	Space for household waste*	0	0	Space for household waste*	0	0
Was 2: Site Waste Management Plan	SWMP to be used*	0	0	SWMP to be used*	0	0	SWMP to be used*	0	0	SWMP to be used*	0	0
Hea 4: Lifetime Homes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Compliance	4	4.667
Mandatory points	–	–	10.776	–	–	14.541	–	–	25.072	–	–	33.505
Total points required for Level	–	–	57.000	–	–	68.000	–	–	84.000	–	–	90.000
Optional points required for Level	–	–	46.224	–	–	53.459	–	–	58.928	–	–	56.495

* Full details in the Code for Sustainable Homes Technical Guide¹

Table 5.4: Mandatory and Optional Scores for Code Levels 3 - 6
Source: Christopher Gaze and others, *The Code for Sustainable Homes simply explained*, 2nd edn (Watford: IHS BRE Press, 2010), p. 3.

A number of additional categories introduce mandatory requirements. These typically take two forms, either in the form of a minimum mandatory requirement fixed at each level of the Code, for example Mat 1 requires 3 out of 5 of the main construction elements to be specified A+ to D in the Green Guide. Or as specific exemplary targets to be attained at Code level 6, for example, Hea 4 requires compliance against Lifetime Homes.

All other credits are considered to be optional or tradable allowing complete flexibility over the design and specification of a dwelling to attain lower levels of the Code. In order to attain Code Level 5 and 6 the majority, 78% and 85% respectively, of these optional credits must be achieved.

Table 5.5: Dwelling Emission Rate credit scores
Source: Department for Communities and Local Government, *Code for Sustainable Homes: Technical Guide 2008* (London: Communities and Local Government Publications, 2008), p40.

% Improvement of DER over TER	Credits	Mandatory Levels
≥ 10%	1	Level 1
≥ 14%	2	
≥ 18%	3	Level 2
≥ 22%	4	
≥ 25%	5	Level 3
≥ 31%	6	
≥ 37%	7	
≥ 44%	8	Level 4
≥ 52%	9	
≥ 60%	10	
≥ 69%	11	
≥ 79%	12	
≥ 89%	13	
≥ 100%	14	Level 5
'Zero Carbon Home'	15	Level 6

Table 5.6: Dwelling Emission Rate credit scores as amended for The Code for Sustainable Homes 2010 with points reallocated.
Source: Rosemary Thomas, *Policy Clarification Letter CL-04-10 : Planning for Sustainable Buildings - Update to the Code for Sustainable Homes* (Cardiff: Department for Environment and Sustainability, 2010), p4.

% Improvement of DER over TER	Credits		% Improvement of DER over TER	Credits
0%	Part L 2006 Minimum Standard	Baseline moves to reflect Part L 2010 25% improvement required through Building Regulations Credits 1-5 reallocated		Part L 2010 Minimum Standard
≥ 10%	1			
≥ 14%	2			
≥ 18%	3			
≥ 22%	4			
≥ 25%	5	← - - - - Level 3 - - - - →	0%	1
≥ 31%	6	← - - - - Planning Policy - - - - →	≥ 8%	
≥ 37%	7		≥ 16%	2
≥ 44%	8	← - - - - Level 4 - - - - →	≥ 25%	3
≥ 52%	9		≥ 36%	4
≥ 60%	10		≥ 47%	5
≥ 69%	11		≥ 59%	6
≥ 79%	12		≥ 72%	7
≥ 89%	13		≥ 85%	8
≥ 100%	14	← - - - - Level 5 - - - - →	≥ 100%	9
'Zero Carbon Home'	15	← - - - - Level 6 - - - - →	'Zero Carbon Home'	10

5.05.3 APPLYING THE CODE TO INNOVATIVE CONSTRUCTION SYSTEMS

The Code is designed to deliver complete flexibility for achieving sustainable house design, and subsequently many of the factors to consider when designing to the Code are project specific. Factors such as site organisation, ecology, and construction impact, waste management and sourcing of materials, and community or mains energy availability are largely out of the control of a generic specification for house design. It is therefore common for identical dwellings on different sites, or even on the same site, to attain different ratings within the Code structure.

In the development of a system build performance specification it is not possible to target a specific Code level due to the number of project specific factors. However it is possible to establish an approach to the Code, which targets credits that can be assumed to be generally applicable. These could include credits assigned to the design and specification of the building fabric or those that could be designed into a standard pattern book. These factors can be considered within three issues, building fabric, materials and design.

BUILDING FABRIC

The energy performance of homes is assessed under Category 1 Energy and Carbon Dioxide Emissions. Credits are awarded based on the Target Emission Rate calculation methodology using a notional dwelling of the same size and shape as the proposed, designed to meet Building Regulations Part L 2006. Code for Sustainable Homes 2007 awards the first credit for a 10% improvement over the TER, with a maximum of 15 credits awarded for a 'Zero Carbon' home where the net carbon emissions resulting from all anticipated energy use is zero. At each level of the Code structure, a mandatory percentage improvement is allocated. These targets are shown in Table 5.5.

A further two credits are awarded based on the Heat Loss Parameter (HLP) of the building fabric. HLP is a measure of heat loss through the fabric of the building due to thermal bridging, ventilation and air leakage and is calculated as part of the SAP calculation.

Categories Ene 1 and Ene 2 have been subject to considerable amendment for the 2010 edition of the Code in order to reallocate points following the inclusion of a 25% mandatory reduction in Carbon emissions over 2006 Building Regulations in Building Regulations Part L 2010. This is illustrated in Table 5.6

In addition Ene 2 has been significantly revised to encourage a fabric first

Table 5.7: Fabric Energy Efficiency credit scores
Source: Department for Communities and Local Government, *Code for Sustainable Homes: Technical Guide 2010* (London: Communities and Local Government Publications, 2010), p40.

Dwelling Type ¹		Credits ²	Mandatory Levels
Apartment Blocks, Mid-Terrace	End Terrace, Semi-Detached & Detached		
Fabric Energy Efficiency kWh/m ² /yr			
≤ 48	≤ 60	3	
≤ 45	≤ 55	4	
≤ 43	≤ 52	5 ³	
≤ 41	≤ 49	6	
≤ 39	≤ 46	7	Level 5 & 6
≥ 35	≤ 42	8	
≥ 32	≤ 38	9	
Default Cases			
None			

approach to sustainable home design.⁴¹ The previous Heat Loss Parameter calculation has been replaced by an award system based on 'Fabric Energy Efficiency' expressed in kilowatt-hours of energy demand per m² per year, kWh/m²/yr. This is calculated using SAP 2009 and is determined by air permeability, fabric U-values, thermal bridging, thermal mass and gains from solar, lighting and appliances. 9 credits are available based on a range of ratings from 60kWh/m²/yr to 32 kWh/m²/yr as shown in Table 5.7.

A fabric first approach has been the focus of a number of research projects including the AimC4 consortium, which includes major developers Stewart Milne Group, Crest Nicholson plc and Barratt Development plc. The approach aims to deliver Code 4 homes by developing design and build processes to deliver high performance fabrics that reduce the need for low and zero carbon technologies. Research suggests that this approach can successfully deliver homes to Code 3 however the demands of Code 4 are likely to require the provision of a minimal amount of renewables such as solar hot water panels.

The SAP calculation system employed by the Code to determine energy performance permits a broad amount of flexibility for building fabric performance without establishing minimum or recommended targets for U values. It has not therefore been possible to establish definitive performance targets for the building fabric through a study of Code literature. In developing a specification for building fabric, it would be useful to establish elemental target U values in order to provide an appropriate base for meeting the building fabric and dwelling emission rate requirements of the Code. Therefore a brief analysis of case studies, Code literature and research studies has been performed to establish typical fabric performance including elemental U values, air tightness and thermal bridging. The findings can be seen in Table 5.8, see over.

MATERIALS AND CONSTRUCTION

The Code employs the Green Guide assessment rating for materials when determining credits against Mat 1 Environmental Impact of Materials. The Green Guide employs a rating system of A+ to E to describe the relative environmental impact of construction materials commonly used by the main construction sectors, including Domestic. A rating of A+ represents the best environmental performance or least environmental impact and E represents the worst.

Credits are assigned by the Code for each of the five key building elements; roof, external walls, internal walls, upper and ground floors, windows. A Green Guide rating of A+ is rewarded with 3 credits, and a maximum of 15 credits are available. To achieve a Code rating at any level a minimum of 3 of the elements

41 Building 4 Change, *Code for Sustainable Homes pushes 'fabric first' approach* (Watford: BRE Trust, 2010)
<<http://www.building4change.com/page.jsp?id=560>> [accessed on 14 May 2012]

	Building Regulations		Kingspan Solutions					Concrete Centre				Lukas Lang	Skandia	Zenit	Potton
Performance Criteria	2006 L1A	2010 L1A	CODE 3	CODE 4	CODE 5	CODE 6	LIGHTHOUSE	Spec 1	Spec 2	Spec 3	Spec 4	Building System	Hus	Potton	Kingspan
U Values															
Walls	0.35	0.3	0.25	0.2	0.16	0.11	0.11	0.28	0.2	0.2	0.15	0.19	0.23	0.2	0.19 - 0.22
Ground Floor		0.25	0.2	0.2	0.16	0.11	0.11	0.18	0.18	0.18	0.15	0.19	0.2	0.12	
Roof		0.2	0.14	0.14	0.14	0.11	0.11	0.11	0.11	0.11	0.11	0.17	0.13 - 0.15	0.19 - 0.2	0.18 - 0.2
Doors		2													
Windows		2	1.5	1.2	0.8	0.8	0.7	1.5	1.5	1.5	0.8	1.56	1	1.2	
Airtightness															
Fabric		10	3	1	1	1	1	5	5	5	2				
Windows			2												
Thermal Bridging															
Fabric		0.15					0.045								
APPROXIMATE STANDARD	BR 2006 L	BR 2010 L	CODE 3	CODE 4	CODE 5	CODE 6	CODE 6	CODE 3-4	CODE 3-4	CODE 3-4	PASSIVHAUS			CODE 3+4	CODE 3+4
Heat Loss Parameter		1.6 - 1.8													
Target Fabric Efficiency															
Price £ per m²												770-2000	1075-1500		1028-1268
Estimated % Over Standard															

	NHBC		Good Homes Alliance				Energy Saving Trust						ZERO CARBON HUB			
Performance Criteria	Case Study 1	Case Study 2	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Code Spec	Greenwatt Slough	CODE 3	CODE 4	CODE 5	CODE 6	4 Storey Apt. Block	Mid Terrace	End Terrace/ Semi	Detached
			The Old Apple	CO2 Zero	Norbury Court	Mid Street										
U Values																
Walls	0.2	0.2	0.14	0.1	0.29	0.14		0.12	0.25	0.2	0.15		0.18	0.18	0.18	0.18
Ground Floor	0.25	0.2	0.15	0.1	0.21	0.14		0.1	0.2	0.2	0.15		0.18	0.18	0.18	0.14
Roof	0.13	0.13	0.12	0.1	0.2	0.13		0.1	0.13	0.13	0.13		0.13	0.13	0.13	0.11
Doors	1	1	1.1	1.0	2	1.2		0.88	1.5 - G, 1.0 - S	1.5 - G, 1.0 - S	0.8	0.8				
Windows	1.2	0.8	1.2	1.2	1.2	0.8		0.8	1.2 - 1.5	0.8 - 1.5	0.8	0.7	1.4	1.4	1.4	1.3
Airtightness																
Fabric			3	1.2	(5.63)	3 (4.9)		2	3	3	3		3	3	3	3
Windows																
Thermal Bridging																
Fabric								0.04					0.05	0.05	0.05	0.04
APPROXIMATE STANDARD	CODE 3	CODE 4	CODE 5	CODE 5	CODE 3	CODE 5		CODE 6	CODE 3	CODE 4	CODE 5	CODE 6	CODE 5+6	CODE 5+6	CODE 5+6	CODE 5+6
Heat Loss Parameter		1.6 - 1.8						0.6 - 0.8								
Target Fabric Efficiency								20 - 25								
Price per m²			1375	1428	950	1850		2610								
Estimated % Over Standard				15%	£7500/unit	20%		28.5%								

Table 5.8: Study of Thermal Performance of Precedents including Construction Systems and Best Practice Case Studies

must be rated at A+ to D in The Green Guide. A brief search finds that the majority of timber based construction elements achieve a rating of A or A+.⁴²

A further 9 credits are available for the responsible sourcing of materials, including basic building elements and finishing elements. In relation to timber, responsible sourcing is considered to be achieved when 100% of the timber employed in the main elements are legally sourced and a Chain of Custody certificate is available to document the chronological history of the product from forest to consumer.

Credits assigned to Material categories have a relatively low weighting in the Code structure, however when combined with credits available for sustainable construction processes, they total nearly 9% of the total points available. Was 2, Man 2 and Man 3 relate to waste generated through construction, construction management, and site impacts caused by construction. MMC and off site construction offers great potential to meet the requirement criteria to achieve the majority of these available credits.

DESIGN

The design and layout of a house is responsible for delivering a large number of credits in the Code structure. In addition to demanding a minimum Code requirement, the standards associated with publicly funded affordable housing delivery overlap considerably with code criteria. For example the HC's Design and Quality Standards deliver a minimum 28 points under the code and the English Partnership's Quality Standards determine a minimum of 23.5 points.⁴³ Lifetime homes is heavily weighted within the Code delivering a maximum of 4 credits or 4.66% if all 16 criteria are met.

The Code credits a number of space requirements that can be considered as easy credits to incorporate into house design. These include Ene 4 Drying space, Ene 8 cycle storage, Ene 9 Home Office and Was 1 Storage of non-recyclable waste and recyclable household waste. There is a determined specification for these additions and if integrated they can deliver 8.6% of the Code credits.

An additional 2 credits are dedicated to the design of the building footprint; this is included to encourage efficient land use. 1 credit is therefore assigned to houses that achieve a net internal floor area: net internal ground floor area of 2.5:1 with a second credit awarded to those achieving a ratio of 3:1.

Daylighting is an important factor in the design of Code assessed homes. 3 credits are awarded for Hea 1 Daylighting however its influence is much greater, providing the opportunity to improve thermal performance through the use of

42 Jane Anderson and Nigel Howard, *The Green Guide to Housing Specification* (Watford: IHS BRE Press, 2000), pp 8-25.

43 Christopher Gaze and others, *The Code for Sustainable Homes simply explained*, 2nd edn (Watford: IHS BRE Press, 2010), p11.

passive solar gains. Daylighting credits are assigned based on the calculated daylight factors affecting the main living spaces with 1 credit assigned for a 2% factor in the kitchen and 1 for achieving at least 1.5% in the other main living spaces. The final credit is assigned if 80% of the working plane, ie a notional surface at 0.85m above floor, in the dining and living room, kitchen and home office receives direct light from the sky.

These design factors should be considered closely when developing a pattern book of house types.

5.05.4 THE PASSIVHAUS STANDARD

The Passivhaus standard was developed in Germany in the 1990s with the first dwellings completed in 1991. Since 2000 the Passivhaus standard has become increasingly widespread with over 30,000 buildings realised across the world.

Passivhaus builds on the traditional theory of passive design; a passive solar strategy provided by a highly glazed south façade or sun space is combined with a high thermal efficiency and natural ventilation to reduce space heating and artificial lighting requirements. However the critical difference is the incorporation of a highly efficient active ventilation system that preheats incoming fresh air using heat gained from activities such as cooking, water heating, and appliances to enable a much greater flexibility of design.

The Passivhaus standard states that the energy required for space heating must not exceed 15kWh/(m². a) and the total primary energy demand must not exceed 150kWh/(m². a). To achieve this, the following minimum standards are required;⁴⁴

- U values for external walls, ground floors and roofs must be a maximum of 0.15 W/m²k
- U values of windows and doors must be a maximum of 0.8 W/m²K for both frame and glazing, typically requiring triple glazed, thermally broken frames and insulated doors
- Thermal bridging must be minimised and ideally eliminated
- Maximum airtightness values of 0.75 m3/m²hr or 0.6 air changes per hour at 50 pascals
- Whole house mechanical ventilation with heat recovery delivering a minimum 75% efficiency and a low specific fan power.

The basic principle of the standard is to make best use of natural factors to reduce the demand for space heating and energy consumption. Although Passivhaus does not specifically establish a ‘Zero Carbon’ specification, it is considered by many to be the answer to low carbon, low energy design and is

44 Passivhaus, *The Passivhaus Standard : Outline Specification* (Cardiff: Building Research Establishment Ltd, 2011)
<<http://www.passivhaus.org.uk/standard.jsp?id=18>> [accessed 14 May 2012]

increasingly specified for exemplar housing developments in the UK. Dwellings designed to the Passivhaus standard achieve approximately a 75% reduction over Building Regulations 2006 and are typically capable of qualifying for a Code 4 rating under the CSH. The Passivhaus standard delivers a high performance fabric typically surpassing those demanded by the CSH and is recognised as a cost effective alternative to offsetting energy demands by ‘bolting on’ low carbon technologies. The provision of some low carbon technologies in addition to a Passivhaus design philosophy should therefore offer the most cost effective solution to achieving Code level 6 dwellings.

5.06 ECONOMIC PROFILE

5.06.1 ACCEPTABLE COST GUIDANCE

It is expected that all affordable housing units developed using the Social Housing Grant (SHG) is produced at or below figures set out in the Welsh Assembly's Acceptable Cost Guidance (ACG). The ACG is reviewed and published annually by the Housing Directorate as *“Acceptable Cost Guidance/On Costs For Use With SHG Funded Housing In Wales”*. Annex A of the document provides a cost matrix of costs based on land prices and build costs for new developments assessed at a community council level and distinguished by dwelling types from 1 person 1 bedroom flats to 7 person 4 bedroom houses. These figures suggest acceptable levels of scheme costs for SHG purposes. Schemes falling below the ACG figures will not typically be subject to detailed scrutiny. Schemes that fall between 100% and 120% of SHG however may be considered for approval if the additional costs are proved to be justified by local conditions and local needs.⁴⁵

The ACG figures include all development costs including land acquisition and construction costs based on a minimum standard of design and specification determined by the DQR. Supplementary on costs are also set out in the ACG Annex C.

Annex D of the ACG assigns band descriptions to each Local Authority area. Typically these are described as a majority band with exceptional community council areas applied to alternative price bands. Table 5.9 details the 2007 ACG figures as allocated to the 9 'rural' Local Authority areas identified in Chapter 2.0. Table 5.10 shows the recently issued figures for 2011.

5.06.2 PRECEDENT STUDY

Performing a cost assessment of the construction industry without a full context including site locality, is a challenging task. Construction costs are considerably affected by many specific project factors such as site locality and type including geotechnical and climatic factors, international and national markets, quantity and mix of units, and scale of construction.

This is further complicated when assessing the target costs for a house building kit where kit dependent costs do not equate to total build costs, due to many optional specifications such as cladding types, window and door types, internal finishes etc.

The study of ACG figures suggests a range of target build costs for the nine rural authorities of Wales. Therefore the next stage of the cost assessment was to consider a study of the existing house construction industry, focusing particularly

45 Welsh Assembly Government, *Acceptable Cost Guidance/On Costs For Use With SHG Funded Housing In Wales* (Cardiff: WAG, 2007), p. 1.

		Rural Local Authority																	
Dwelling Type	Floor Area	Carmarthenshire Band 1		Ceredigion Band 1		Conwy Band 2		Denbighshire Band 3		Gwynedd Band 2		Isle of Anglesey Band 2		Monmouthshire Band 6		Pembrokeshire Band 1		Powys Band 3	
	Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm
1 Bed 2 Person	50	73 100	1462	73 100	1462	77 000	1540	80 900	1618	77 000	1540	77 000	1540	101 200	2024	73 100	1462	80 900	1618
2 Bed 3 Person - Flat	64	85 200	1331.25	85 200	1331.25	89 500	1398.44	93 800	1465.63	89 500	1398.44	89 500	1398.44	116 200	1815.63	85 200	1331.25	93 800	1465.63
2 Bed 3 Person - Bungalow	58.1	94 800	1631.67	94 800	1631.67	105 400	1814.11	116 000	1996.56	105 400	1814.11	105 400	1814.11	171 300	2948.36	94 800	1631.67	116 000	1996.56
2 Bed 3 Person - House	62	86 500	1395.16	86 500	1395.16	93 800	1512.9	101 000	1629.03	93 800	1512.9	93 800	1512.9	138 800	2238.71	86 500	1395.16	101 000	1629.03
2 Bed 4 Person	77.4	105 200	1359.17	105 200	1359.17	113 800	1470.28	122 400	1581.4	113 800	1470.28	113 800	1470.28	167 300	2161.5	105 200	1359.17	122 400	1581.4
3 Bed 4 Person	82.7	111 500	1348.25	111 500	1348.25	120 100	1452.24	128 700	1556.23	120 100	1452.24	120 100	1452.24	173 600	2099.15	111 500	1348.25	128 700	1556.23
3 Bed 5 Person	88.4	117 700	1331.45	117 700	1331.45	126 900	1435.52	136 100	1539.59	126 900	1435.52	126 900	1435.52	184 000	2081.45	117 700	1331.45	136 100	1539.59
4 Bed 6 Person	103.7	136 600	1317.26	136 600	1317.26	147 200	1419.48	157 900	1522.66	147 200	1419.48	147 200	1419.48	213 100	2054.97	136 600	1317.26	157 900	1522.66
4 Bed 7 Person	110.9	154 200	1390.44	154 200	1390.44	166 800	1504.06	179 300	1616.77	166 800	1504.06	166 800	1504.06	244 600	2205.59	154 200	1390.44	179 300	1616.77
Average Price per Sqm		1396.29		1396.29		1505.23		1613.98		1505.23		1505.23		2181.04		1396.29		1613.98	

Table 5.9: Acceptable Cost Guidance 2007 for alternative dwelling types by rural Local Authority
Source: Welsh Assembly Government, *Acceptable Cost Guidance/On Costs For Use With SHG Funded Housing In Wales* (Cardiff: WAG, 2007), Annex A.

		Rural Local Authority																	
Dwelling Type	Floor Area	Carmarthenshire Band 1		Ceredigion Band 1		Conwy Band 3		Denbighshire Band 3		Gwynedd Band 3		Isle of Anglesey Band 2		Monmouthshire Band 6		Pembrokeshire Band 1		Powys Band 3	
	Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm	Total	Per Sqm
1 Bed 2 Person	51	80 100	1507.59	75 500	1480.39	84 700	1660.78	84 700	1660.78	84 700	1660.78	84 700	1660.78	97 000	1901.96	80 100	1570.59	84 700	1660.78
2 Bed 3 Person - Flat	65	100 400	1544.62	95 200	1464.62	105 600	1624.62	105 600	1624.62	105 600	1624.62	105 600	1624.62	119 400	1836.92	100 400	1544.62	105 600	1624.62
2 Bed 3 Person - Bungalow	58	115 200	1986.21	102 400	1765.52	127 900	2205.17	127 900	2205.17	127 900	2205.17	127 900	2205.17	161 900	2791.38	115 200	1986.21	127 900	2205.17
2 Bed 4 Person	83	122 800	1479.52	112 400	1354.22	133 200	1604.82	133 200	1604.82	133 200	1604.82	133 200	1604.82	160 800	1937.35	122 800	1479.52	133 200	1604.82
3 Bed 4 Person	88	128 300	1457.95	118 000	1340.91	138 700	1576.14	138 700	1576.14	138 700	1576.14	138 700	1576.14	166 300	1889.77	128 300	1457.95	138 700	1576.14
3 Bed 5 Person	94	137 000	1457.45	126 000	1340.43	148 100	1575.53	148 100	1575.53	148 100	1575.53	148 100	1575.53	177 500	1888.3	137 000	1457.45	148 100	1575.53
4 Bed 6 Person	110	159 800	1452.73	147 100	1337.27	172 600	1569.09	172 600	1569.09	172 600	1569.09	172 600	1569.09	206 600	1878.18	159 800	1452.73	172 600	1569.09
4 Bed 7 Person	114	171 200	1501.75	156 100	1369.3	186 200	1633.33	186 200	1633.33	186 200	1633.33	186 200	1633.33	226 400	1985.96	171 200	1501.75	186 200	1633.33
Average Price per Sqm		1383.42		1272.52		1494.39		1494.39		1494.39		1494.39		2181.04		1383.42		1494.39	

Table 5.10: Acceptable Cost Guidance 2011 for alternative dwelling types by rural Local Authority
Source: Welsh Assembly Government, *Acceptable Cost Guidance/On Costs For Use With SHG Funded Housing In Wales* (Cardiff: WAG, 2011), Annex A.

on timber frame construction and considering the existing market for timber frame construction systems.

A study of the Building Cost Information Service identified a number of brief conclusions based on 2009 figures;

- Average price of new build estate housing - £819 per m²
- Average price of timber framed estate housing - £865 per m²

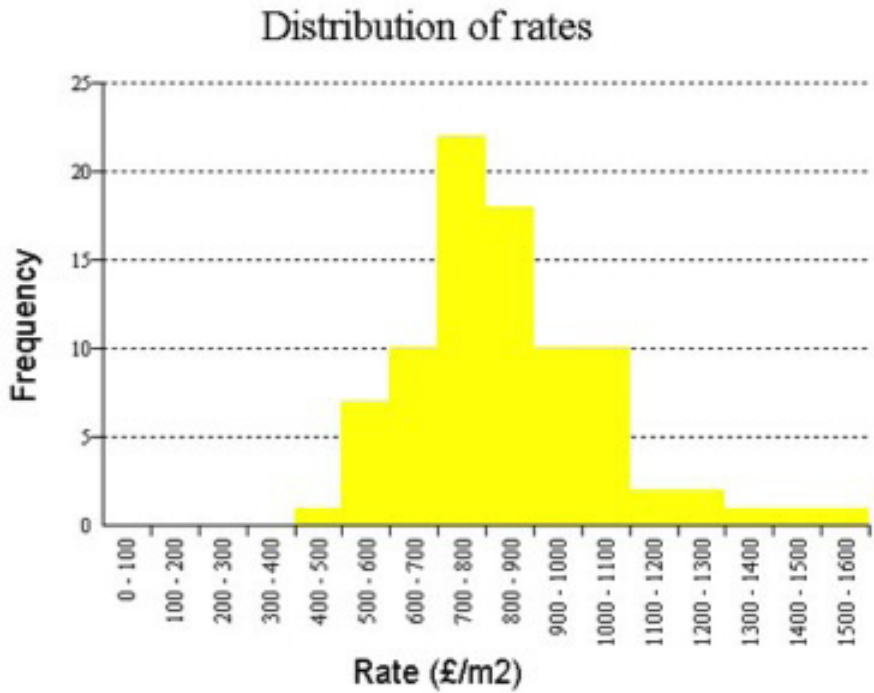


Chart 5.1: Distribution rates for new build estate housing.
Source : Building Cost Information Service

- Average price of new build housing in developments of less than 3 units - £914 per m²
- Chart 5.1 shows the distribution of rates for new build estate housing.

A study performed by the BCIS in 2005 to inform the NAO report *Using modern methods of construction to build homes more quickly and efficiently* presented the following costs findings;⁴⁶

- Brick and Block construction had an estimated range of £599-999 per m² with an average of £799,
- Timber frame construction- range of £599-998 per m² and average of £798,
- Advanced Panel construction- range of £663-1104 per m² and average of £883,
- Hybrid construction – range of £675-1126 per m² and average of £900,
- Volumetric construction- range of £772-1287 per m² and average of £1030,
- These estimates include dwelling costs with prelims apportioned by costs.

46 BCIS. Costing Process. Oct 2005. Page 6

















Housing Cost Study														
Scheme		Client/ Developer/ Manufacturer	Architect	Completion Date	Description	Construction Type	Environmental Standard	Social Housing DQR/ Lifetime Homes	Floor Area	Price of Primary Structure/Kit	Unit Price/ Total cost	Cost of Structure/ Kit Erected/ m2	Cost/ m2	Comments
Selection of Projects														
Waunarlwydd, Swansea			Loyn & Co	Unbuilt	12 terraced 3 Bed 5 Person Houses		Code Level 4	DQR Compliant	105m2		£125,000		£1,190.00	
Clay Field		Orwell Housing Association	RHMA	2008	Rural social housing scheme based on series of gardens with barn-like terraced housing units between.	Timber frame/ Hemcrete	60% reduction in carbon use	Over DQR standards	13x2B 78m2				1300 (1528 inc landscaping)	
									9x3B 99m2 houses					
									4x1B 47m2 flats					
Great Bow Yard		Ecos Homes	Stride Treglowan	2007	12 terraced units and apartments of a rural edge of settlement brownfield site. Total cost £1.5 mill	Timber frame, SIPs, masonry	EcoHomes Excellent	No	1B2P 47m2		140000		£2,978.72	
									2B4P		155,000			
									3B5P 87m2		250,000		£2,873.56	
									4B7P		290,000			
New Islington		Urban Splash/ Manchester Methodist HA	DMFK	2007	14 units 3 Bed two storey terraced units on an urban brownfield site	Load bearing masonry	EcoHomes Excellent	Social housing, DQR, Lifetime homes compliant		Load bearing masonry	1.5 million		£1,128.00	
Whelcofts Yard		Selfbuild	RHMA	2004	3 selfbuild terraced units on a tight urban site	Timber Frame			96m2, 2B4P		341,000		£1,186.00	
Aselated Self Build, Tibury		New Islington & Hackney HA	Sergison Bates	2003	10 terraced Units. Self build case study self build in urban context- local residents taught carpentry/building skills and work with contractor on scheme.	Prefabricated timber frame		Social Housing	total 478m2	Prefabricated timber frame	Total £570,000		£1,192.00	
Good Homes Alliance Code for Sustainable Homes: Case Studies														
The Old Apple Store, Stawell, Somerset		Ecos Homes Ltd and Pippin Properties Ltd	Malcolm McAll	2009	5 Detached and terraced units	Glulam Frame with Orientated Strand Board (OSB)	Code 5						1375 Excluding land costs and fees	
CO2 Zero, Bristol		Logic CDS Ltd	Brandon Lloyd	2009	9 Two bed three storey live-work terraced units	Solid cross laminated timber panels with external insulation	Code 5	Two bed three storey live-work					1428 Excluding land costs and fees	
Narbury Court, Staffordshire		Staffordshire Housing Association and LNL Developments	Sammonds Architectural	2007	7 three bed houses, 1 two bed house, 1 three bed dormer bungalow	Prefabricated timber frame construction	Code 3	7 three bed houses, 1 two bed house, 1 three bed dormer bungalow					950 Excluding land costs and fees	
Energy Savings Trust: Building the first Code level 5 homes														
Mid St, South Nuffield, Somerset		Raven Housing Trust	Harrington Design + Bloomfield	2008	2 Two bed 4 person flats	SIPS system with external insulation, hanging tiles and external render	First Code 5 dwellings completed in UK				334000		2610 estimated at 2030 for Code 3 standard	
Design For Manufacture: Lessons Learnt														
Osley Woods, Milton Keynes		English Partnerships/ George Wimpey	Rogers Stirk Harbour	2007	Suburban, greenfield 145 Semi Detached 3ha, 44 dph	Open Panel System	Code level 2 (potential for 5).	30% Social Housing English Partnerships Quality Standards compliant. Meets DQR and lifetime homes.	Min 76.5 sq m,		13 million		784 (60k house)	
											Type B 2B4P- 81390			
											Type C 3B5P- 84547			
School Road, Hastings		Southern Housing/ William Verry	Radley House Partnership		Rural, brownfield, Terraced 15, Two and three bed houses, 0.223ha, 47dph	Weberhaus Closed Panel system		Social Housing, Lifetime Homes Compliant	Min 76.5 sq m,		2B4P- 63721		£832.95	
Upton, Northampton		Midsummer Housing/ Barnatt Developer	HTA/ Development Design Partnership		165 units. 3.08ha, 49dph	Kingspan light-gauge steel frame and cassettes/ Robertson Timberkit open timber panel/ Celcon thin joint masonry	EcoHomes Excellent	22% Social Housing, Lifetime Homes Compliant	Min 76.5 sq m,		2B4P- 58596		£765.96	
Albion Bywater, New Leeds		Midsummer Housing/ Barnatt Developer	HTA/ Development Design Partnership		Suburban. 151 Units. 3.3ha, 47dp	Kingspan light-gauge steel frame and cassettes/ traditional masonry construction/tradit onal truss roof		20% Social Housing, Lifetime Homes Compliant	Min 76.5 sq m,		2B4P- 67455		£881.76	
Former Penny Lodge hospital, Newport Pagnell		Affinity Sutton/ SixtyK Consortium	Sheppard Robson/ Design Group 3 Architects	mid-2008	68 Units. 1ha, 68dph	Kingspan TEK2 construction system with masonry cladding		30% Social Housing, Lifetime Homes Compliant	Min 76.5 sq m,		70670 per unit		£926.41	
Former Linton hospital, Maldenstone		Town & Country Housing Association/ SixtyK Consortium (Crest Nicholson)	Sheppard Robson	mid-2008	Suburban. 150 Units. 3.8ha, 38dph.	Kingspan TEK2 construction system with masonry cladding		25% Social Housing, Lifetime Homes Compliant	Min 76.5 sq m,		Linton Flat- 61281		£801.06	

Table 5.11: Cost Analysis Study of International Housing Precedents

The data is based on a survey of 50 projects from the BCIS database of Study of Average Prices for new build estate housing.

The second stage of this cost assessment was the consideration of a range of recent housing developments in the form of a precedent study presented in Tables 5.11 and 5.12.

Of particular interest are the costs associated with the Design for Manufacture £60k House competition which posed the target cost of £784 per m². Included in this target price is the cost of the supply, delivery and erection of superstructure, foundations, and services ready for occupation, all preliminaries, design costs, fees and profit for each dwelling.⁴⁷ Whilst not all of the competition projects have met these target costs, the average cost range of £54,200 – £77,353 still displays an exemplary achievement for house construction.

The precedent study considers a number of innovative and conventional modern methods of construction that are currently available to the UK construction industry. High performance build systems achieving a Code level 5 such as RuralZed and Cloudnine are stated to have a build cost of approximately £1500 per m². These costs are similar to the costs associated with the Good Alliance's Code 5 housing studies in Bristol and Somerset, with build costs of £1428 per m² and £1375 per m² respectively. Code 4 variations of these systems fall in the range £1200-1400, somewhat higher than the Code 4 social housing proposal by Loyn and Co for Waunarlwydd, Swansea.

The study of a number of major timber frame kit suppliers provides further detail concerning total build costs and kit costs. In the case of Scandia Hus and Potton, Pattern books are available alongside prices for the associated building kits. The Potton price list ranges from £247 per m² to £367 per m² for the supply and erection of closed panel kits. The guide also provides an illustrative total build cost based on 8 proposed designs. This suggests that the timber structural frame would typically account for approximately one third of the total build cost excluding land costs, fees, connection to services and landscaping. Scandia Hus publish higher initial kit costs of between £460 and £650 per m² and recommend a rule of thumb of between £1075-1500 per m² be applied to total build costs. In both cases the construction fabric is designed to achieve code levels 3 or 4.

A key limitation of this data and assessment method is the lack of directly comparative prices. Available data is rarely presented in a form that can be directly compared with data from other projects, with items such as landscaping, fees, preliminaries, and land acquisition costs, having a critical and largely unidentified affect on published data. It has not been within the scope of this cost assessment study to perform a thorough economic assessment of the construction industry

47 Homes and Communities Agency, *Design for Manufacture Lessons Learnt 2* (London: Homes and Communities Agency, 2010) Page 72









Green Building Store																			
Derby Dale Passivhaus, West Yorkshire		Groff + Kate Tunstall/ Green Building Store	Dennis O'Sullivan	Apr-10	Rural three bed detached house. First certified Passivhaus in the UK to use traditional cavity wall construction.	Traditional Cavity wall with coursed natural Stonework. Traditional truss roof.	Passivhaus Compliant							141000				£1,195.00	
		Housing Systems																	
Rural Zed		ZED Factory	ZED Factory	unbuilt	Zero Carbon housing kit for rural/ suburban applications	Post and Beam Laminated Timber Frame with High Thermal Mass Int'l	Code 3	Compliant with Lifetime Homes	90m2	89,000-125,000	139,000 - 175,000 - erected							£989.00	£1,146.00
							Code 4		90m2									£1,280.00	
							Code 5		90m2									£1,500.00	
							Code 6		109m2									£1,606.00	
Balehaus		Modcell	White Design		Balehaus is a zero carbon whole house solution that's uses Modcell Straw and Modcell hemp cladding panels	Prefabricated cladding panels of laminated timber and Straw or Hemp, with cross laminated	Zero Carbon	Compliant with Lifetime Homes	Type A 386P 107m2										
Cloud nine		Cloud nine Living			A range of modular unit house designs manufactured in Poland. A high performance closed panel system is also available.	High performance modular construction system using I section studs, Fermacell and wood fibre insulation			2B 64m2	93000	£86,000-							£1,453.00	BLUDE V4/V5
									3B 69.5m2	99000	169,000,							£1,425.00	BLUDE V3
									2B 72.3m2		excluding groundworks, cransage, fees								MARAZION TERRACE
									3B 103m2	144000								£1,392.00	ZELAH SD
									3B 103m2									£1,496.00	ZELAH SD
									3B 118m2	£169,000								£1,432.00	LAMORNA 1
Zenit		Kingspan Potton			A range of design 'cores' which can be configured in any arrangement with flat or pitched roof elements to create contemporary styled homes	Laminated timber portal frames combined with the Kingspan TEK® Building System	Code 3-4 as standard		2B 79	66700	7000- Erection	£932.91						ZENIT 01	
Lukas Lang		Lukas Lang Building Technologies				Laminated Post and Beam Frame with int'l			4B 138	82400	11400- Erection	£679.71						ZENIT 02	
									4B 199	106400	16300- Erection	£616.58						ZENIT 03	
									3S 4B 195	127300	17100- Erection	£740.51						ZENIT 04	
									3S 4B 238	148000	21000- Erection	£710.08						ZENIT 05	
									4B 242	114300	28900- Erection	£558.26						ZENIT 06	
Scandia Hus		Scandia Hus			Introductory house designs using a standard timber frame house kit	Closed panel system	Code 3 and 4		3B 156	79,350	9965- Erection	£572.53	1075-1500	The Bornholm Bungalow					
									4B 260	106,620	13090- Erection	£468.12	1075-1500	The Lappland Chalet					
									5B 441	180,195	24355- Erection	£463.83	1075-1500	The Woodlands Traditional					
									4B 219	£106,740	11240- Erection	£538.72	1075-1500	The Tithe Barn					
									4B 282	£164,200	16380-Erection	£640.35	1075-1500	The Chamonix Contemporary					
Potton		Kingspan Potton			Wide range of house types for self build or contractor let construction	Closed panel system	Code 3 and 4		4B 162	£5,700	£204,921	£343.83	£1,268.00	Heritage Caddon					
									4B 219	80,500	£260,593	£367.58	£1,189.00	Heritage Gransden					
									4B 160	£33,000	£194,342	£331.25	£1,215.00	Rectory Papslewick					
									5B 284	£94,300	£324,148	£332.04	£1,141.00	Rectory Mlchester					
									4B 152	£41,950	£165,388	£275.99	£1,089.00	Shire Ashwell					
									5B 238	£92,250	£244,931	£261.55	£1,028.00	Shire Waterford A					
									184	£45,600	£202,112	£247.83	£1,099.00	Bungalow,Claybrook					
									224	£81,850	£251,118	£365.40	£1,121.00	Barn Shalford B					

Table 5.12: Cost Analysis Study of International Housing Precedents ... continued.

	Performance Standard	Approximate Construction Price per Sqm
RuralZed, Zed Factory	Code 3	1,146
	Code 4	1,280
	Code 5	1,500
	Code 6	1,606
Balehaus, Modcell	Zero Carbon	
Kingspan Tek, Zenit	Code 3 and 4	558 - 932 (cost of kit)
Skandia Hus	Code 3 and 4	1,075 - 1,500
Kingspan Potton	Code 3 and 4	1,028 - 1,268

Table 5.13: Construction costs of a sample of the key precedent commercially available whole house construction systems.

or the timber frame kit build market. In order to identify a precise target cost, the following studies could be completed;

- A comparative study of recent cost data from completed constructions including elemental breakdowns. Projects that would be of greatest value are; timber frame constructions, rural construction sites, specifically those in Wales, developments up to 10 houses, and Code 4–6 certified homes.
- A comparative study of building systems, specifically timber frame construction systems. This could take the form of a tender assessment with full elemental breakdown including assembly costs and associated non-system costs, based on a given design or specification.

However based on the precedent study and review of recent studies a target cost of between £1200-1500 per m² would seem to be necessary to be competitive with the existing construction industry and to meet the requirements for affordable housing.

Based on the Potton build guide this would suggest a closed panel frame price of between £400 and £500 per m². However it is largely unknown at this point in the study what level of total build costs will be directly determined by the construction system.

5.07 PERFORMANCE SPECIFICATION

Based on this assessment of current and future standards, it is proposed that the following performance specification is an appropriate target for the design of a whole house construction system for affordable rural housing.

This assessment of standards has identified a number of factors which are unlikely to directly affect the design and specification of homegrown timber components. However it is proposed that many of these additional factors will inform the generation of an affordable housing pattern book.

It has generally been determined that compliance with national and international performance standards is the appropriate course of action in the development of a system build. However there is a clear hierarchy of importance when considering the application of affordable housing. First and foremost the economic profile of the system is fundamental to its appropriateness to this application. For a system to be taken up by the industry to any scale, it must be at least competitive with the existing market.

It is not within the scope of this research study to ensure that the proposed construction system is fully compliant with the requirements for structural and construction products. This element of the research will be guided by skilled consultants as part of the broader Ty Unnos development project. In the following chapters, the implications of this specification will be considered in terms of design and buildability. However, it is assumed that the target specification identified by consultants is appropriate and fundamental to realise the objectives of this study.

The remaining areas of this performance specification are identified as a target specification, to establish a reasonable foundation for a system build that can be adapted to the differing demands of affordable housing. Of particular consideration is the thermal performance of a system build. It is not proposed that this target specification will establish a singular solution for all applications but rather provide an appropriate performance base on which additional specifications can be efficiently applied to tailor performance standards to the intended application.

This performance specification will be applied to each element of the research methodology to inform and act as a benchmark against which the findings of each study can be tested.

Performance Criteria	Standard
DESIGN PRINCIPLES	
Materials	Where possible incorporate standard production homegrown softwood, predominantly Sitka Spruce, making use of readily available standard dimensions
Forest Industry	Make use of low technology manufacturing processes where necessary appropriate to the Welsh primary and secondary processing industries
Construction Industry	Incorporate standard practice where possible and where innovative processes are required, ensure dissemination of construction processes are appropriate to the construction industry in Wales and consider the requirement for large scale construction plant on sites in rural localities.
Rural Wales	Enable flexibility in design to encompass wide variations in Vernacular styles, densities and materials for Rural Wales.
TESTING + CERTIFICATION	
Structural Specification	All structural performance to be designed to BS EN 1996-1 Eurocode 5: Design of Timber Structures
Whole System Certification	System to be designed to ETAG 007 Timber Building Kits in conjunction with an approved certification body
CONSTRUCTION STANDARDS	
NHBC	Design to meet NHBC requirements for cover either by;
	Design for full compliance with NHBC Standards, or
	Compliance with NHBC Standards through full approved body certification
SPACE AND QUALITY STANDARDS	
Design Quality Requirements	Design to be fully compliant with the DQR as published by the WAG
Lifetime Homes	Design to be full compliant with all 16 principle of Lifetime Homes
Secure by Design	Design to be fully compliant with Secure By Design
THERMAL PERFORMANCE	
Dwelling Emission Rate	A Minimum 55% improvement over 2006 Building Regulations in line with the proposed devolved Welsh Building Regulations 2013
U Values	
	Walls0.15 - 0.2
	Ground Floors0.15 - 0.2
	Roof0.11 - 0.14
	Doors1
	WindowsBand A or B 0.8 - 1.5
Airtightness	
	Fabric1 -3
	Windows1 -3
Thermal Bridging	
	Fabric0.04
Green Guide	All main elements of the construction ie external and internal walls, floors, roofs, windows and doors to achieve a rating of A+ to D in the Green Guide
ECONOMIC PROFILE	
Acceptable Cost Guidance	Acceptable Cost of 1396 per square metre
	Based on a maximum acceptable cost of the lowest band rating
	All rural local authorities have an acceptable cost range of £1396 - 2181 per square metre
Target Range	£1300 - 1500 per square metre

Table 5.14: Performance Specification for affordable rural housing.

Chapter 6.0

Component Testing And Development

a narrative of the prototyping, testing and development of engineered homegrown
timber components

6.01 INTRODUCTION

In the following chapter, the development of homegrown timber construction components will be reviewed, providing a narrative of the decision making that has guided this process and their combination into a system build. This will conclude in the formation of a matrix of homegrown timber components which have been tested for appropriateness to domestic applications, including a description of their respective performance characteristics.

The Ty Unnos Feasibility Study proposed a radical departure from existing construction methods, suggesting an innovative construction system comprising;

- A modular glue-laminated post and beam structure, maximising the use of readily available, standard lengths and sections of Sitka Spruce;
- A modular panel system based on Spruce or other softwoods that can provide flexibility in use and adaptation in the future including wall, window and door positions;
- Make use of basic mechanical fixings such as brackets, plates and screws, to maximise the potential to disassemble the structure later.

The study took inspiration from Jørn Utzon's Espansiva system, as considered in section 3.10, a standardised additive system for low cost, low density rural housing.¹ A selection of standardised monopitch single storey modules, designed as standard room types, could be combined to create a wide variety of spatial arrangements and house types.

Developing this as a precedent, the proposed system was considered as a series of modular rooms varying in sizes from 1.2m x 3m to 4.8m x 3m, or from entrance lobby to small bedroom to kitchen to living room.² Modular rooms would be created from prefabricated hollow box section beams, using readily available lengths of Sitka Spruce. These beams would be connected to form portal frames. The proposal was conceived as a whole house construction system and therefore included a system of thermal components to provide floor, wall and roof infill. Infill components would be designed to use locally sourced natural insulations such as hemp, sheep's wool and Warmcell insulation thus creating a locally sourced whole house system which combines low-tech manufacturing with fast build times and insulation values approaching 0.15W/m2K.

Following its publication and subsequent dissemination, the study led to the formation of a multidisciplinary team to pursue the development of engineered homegrown timber construction components. As previously described, this has been the focus of a number of complementary research and development

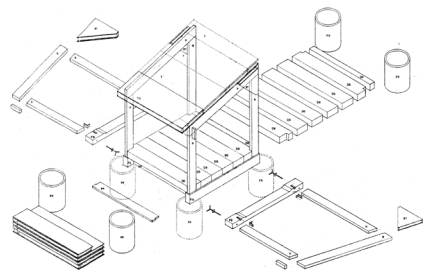


Figure 6.1: Axonometric diagram of Utzon's Espansiva System
Figure 6.2: Proposed Ty Unnos homegrown timber components

1 Jørn Utzon, *Jørn Utzon Logbook Vol. V : Additive Architecture* (Hellerup: Edition Blondal, 2009), pp 132-178.
2 Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007), p. 19.

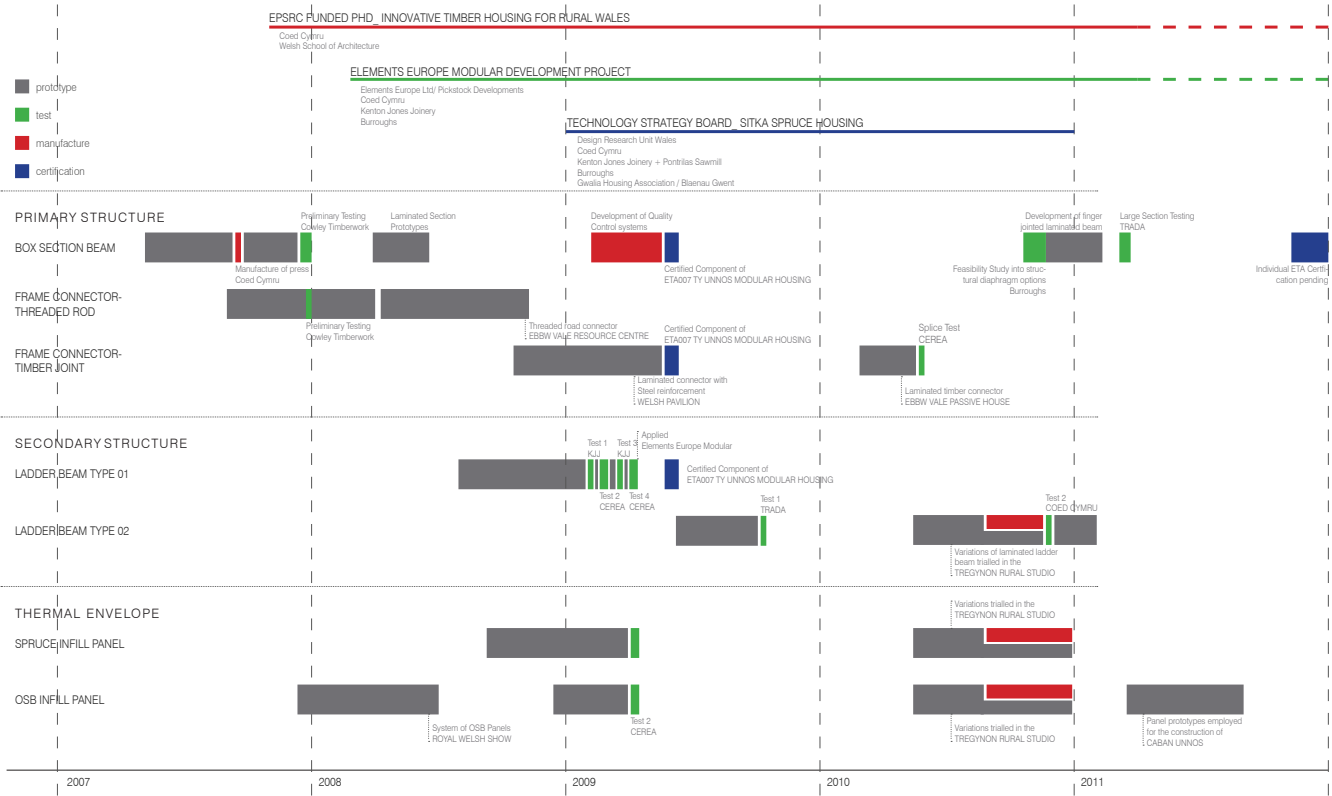
projects, including this study. Managed predominantly by specialist timber engineers Burroughs, the Project Team have focused their attention on a number of alternative timber components that can be adapted to a range of MMC forms. These can be considered in 3 areas of structural and construction function;

1. Primary Structure : a high capacity structural member for combination into a load bearing structural frame appropriate to the scale of domestic construction
2. Secondary Structure : an engineered component capable of spanning between primary structural members
3. Thermal Envelope : a system of providing a high performance thermal envelope using off site manufacturing methods.

The Project Team have embarked upon a four year development programme that has included prototyping, physical testing, structural modelling and development of manufacturing processes. This programme is described in Table 6.1. Under the guidance of Burroughs, this process has set out with the objective to resolve construction solutions that can, if desired, meet the criteria for certification under ETAG 007: Timber Building Kits.

In the following chapter, the development of each construction element will be reviewed. Attention will be drawn to the direct contribution made by myself to this development process, which includes prototyping components, performing physical testing and contributing to the future direction of development.

Table 6.1: Realised programme of homegrown timber construction component testing and development.



6.02 PRIMARY STRUCTURE

CONTRIBUTIONS TO THE DEVELOPMENT OF THE PRIMARY STRUCTURAL COMPONENTS INCLUDE;

- Preliminary analysis of thermal performance of box beam in relation to building envelope.
- Consultation regarding target and realised box beam capacities when applied to the design of house types.
- Detailed design of box beam when applied as part of a whole house construction system, including integration of services, analysis of thermal performance, compliance with building standards.
- Review and feedback to the Project Team on the opportunities and limitations resulting from the box beam specification and manufacturing process.
- Design and prototyping of 2 dimensional and 3 dimensional connectors and consultation regarding opportunities and limitations of alternative options.
- Detailed design and analysis of diaphragm panels when applied as part of a whole house construction system, resulting in further analysis of options for providing racking resistance.
- Review and feedback to the Project Team on the opportunities and limitations resulting from the construction/assembly process when applied to prototypical studies.

6.02.1 SITKA SPRUCE BOX SECTION

Welsh grown C16 spruce is readily available in a range of standard lengths to 4.8m, in standard thicknesses of 47mm and widths from 75mm to 250mm.

As detailed in Chapter 3.0, although Welsh spruce has poorer structural properties than imported softwoods, it is its tendency to twist during drying that limits its use in construction. If a structural frame is to consider using solid section Welsh Spruce, the sections required to achieve spans appropriate for domestic construction, ie 4.5 - 6m, would be too large to cut without boxing the heart or centre of the tree. Large sections such as these would be extremely prone to distortion when cut.³ It was therefore proposed that a primary structural element could be developed using smaller sections of timber combined to form a stable and high capacity section.

Glue lamination of thinner sections to form solid posts and beams has established a considerable market and is increasingly competitive with concrete and steel.



Figure 6.3: Standard C16 Sitka Spruce ready for processing
Figure 6.4: Assembling the machined components,
Figure 6.5: Pressing the box section whilst curing using pneumatic pressure from a standard workshop compressor and lengths of fire hose.

3 Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn., p. 14.



a) Select 2 lengths of C16 Spruce 225 x 47mm for flange timbers and 2 lengths of 150 x 47mm for web timbers, with visual assessment of distortion and quantity of knots.



b) Plane and mould web timber to give a section of 150 x 40mm with tapered tongues to each long edge.



c) Plane and mould the flange timber to give 2 sections of 210 x 40mm with 2 longitudinal grooves.



d) Working immediately adjacent to the pneumatic press on an extended table, polyurethane glue is applied to the prepared grooves in the bottom flange.



e) Web timbers are dropped into the profiled grooves.



f) The tongue and groove profile holds the assembled box stable and square during assembly. Adhesive is then applied to the upper edge.



g) The upper flange is located onto the tongues of the web timber and the assembled box pushed into the press, against rear uprights.



h) A compressor fills a doubled line of fire hose to lift the table bed and compress the box against the top restraints of the presses. Clamps to the rear uprights ensure section is square.



i) Once cured remove from press, remove excess glue and trim box section to length.



PREVIOUS PAGE

Figure 6.6: Assembly sequence of Sitka Spruce box section using the pneumatic press at Kenton Jones Joinery.

THIS PAGE

Figure 6.7: Box section under compression showing the tongue and groove geometry of the corner housing joint.

Figure 6.8: Cramping press set up at Coed Cymru with box section in place.

Although it is considered feasible to use Welsh softwood in the production of Glulam sections, it typically involves a slow and expensive manufacturing process. Due to the small scale manufacturing and capital potential of the Welsh industry it is unlikely that a laminated system can be widely applied.

Initial studies performed by Coed Cymru looked at creating box sections from wide spruce planks formed into a hollow box using shoulder housing joints. Trials found that the geometry of this housing joint, made up of a profiled tongue in the web sections of the box and a routed groove in the flanges, could successfully stabilise the four sections of timber, and actually resolve minor distortion in sections. The resulting beam was therefore light due to its relatively small quantity of timber, but seemingly very strong and stable. In addition, the hollow section provided an opportunity to integrate thermal insulation into the primary structure and reduce concerns of thermal bridging.

MANUFACTURE

In September 2007 Coed Cymru developed and built a cramping press to enable the repeat manufacture of box beams. The press, shown in Figure 6.8, is structured in steel rectangular section with a fixed top plate and movable base plate. A standard fire hose and air compressor acts as a mechanical force, lifting the base plate and compressing the assembled box beam against the top plate until glue has cured. The jig was constructed for approximately £10,000 and enabled capacity for a length of up to 4.8m and a section depth of up to 300mm.

The process for assembly is shown in Figure 6.6.

INITIAL TESTING

Cowley Timberwork undertook structural testing on the Ty Unnos box section in early 2008, firstly on a simple beam and then in the form of a portal frame. Tests on the box section beam were very promising with consistently high loadings being met with great efficiency.

Cowley Timberwork tested 5 boxes with an increased section dimension of 270 x 210 based on procedures set out in BS 5268-2:2002 in order to verify theoretical assumptions of the maximum span of floor beams.

The test set up employed a hydraulic rig with clamp restraints provided at 5020mm centres, generating a clear span of 4.8m. A design load of 334kg/m was calculated to give a uniformly distributed load of 1678kg. Load is applied using hydraulic rams positioned at 4 points along the beam length, exerting measured load upwards. In addition to end restraints, a number of straps along the beam length provide security against a sudden failure in the beam.

- All five beams were initially taken up to design load for 15 mins to 'bed in' then returned to 0 load.



Figure 6.9: Box beam in vertical deflection test rig showing significant bending.

Figure 6.10: Box beam following failure at centre.

Figure 6.11: Close up of failure originating in the upper boom.

- They were then returned to design load and held for 24 hours with deflection measurements taken hourly.
- Three beams were then loaded to destruction.

This test procedure yielded the following results;⁴

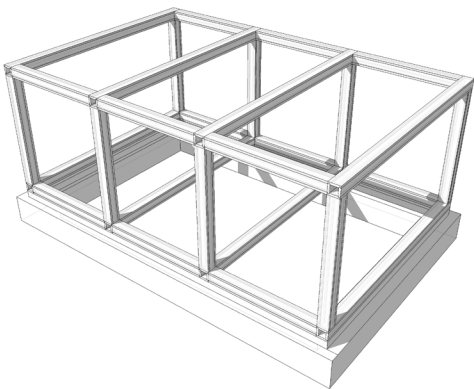
- Beams deflected by 12.2 - 14.5mm when under design load
- When released beams returned to a residual deflection of between 0.0 - 0.3mm
- The three beams failed at 6800kg, 7300kg and 8732kg
- Observations of the destruction tests encouraged confidence in the failure modes of the beams. As loads were increased the beams responded with a number of loud splits and cracks, without any noticeable performance failure. On breakage, which usually occurred after a significant time/load increase from first signs, the beam would fail along a weakness such as a knot or split. Significant warning of potential failure prior to physical failure is a positive strength of timber structural sections in comparison to steel which provides very limited warning of impending failure.

In addition to the structural findings yielded by this process, the tests provided an opportunity to manufacture beams in a higher quantity than previously trialled. The manufacturing process identified the following observations;

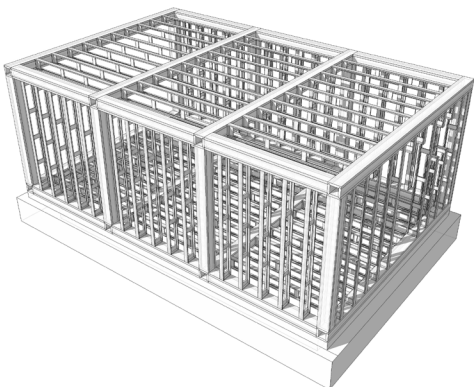
- The 225mm wide timber is still prone to twisting throughout the processing stage and although combining into a box stabilises movement, it can require considerable processing to ensure an accurate square section.
- An initial supply of 225x47mm Sitka Spruce was intensive on machinery, resulting in higher than expected manufacturing costs, a greater quantity of rejected material and a longer manufacturing time. A second stock of timber performed better in all these aspects.
- The conversion of a standard section of 225x47mm was initially proposed to result in a design section of 280 x 220 with 45mm walls however the sections required more processing than first anticipated resulting in a maximum section of 270x210mm with 43mm walls. The actual section was therefore 15% less stiff than the design section.

This initial testing supported analytical modelling to enable the publication of a *Technical Assessment of the Ty Unnos System* by Burroughs. Box sections are modelled as simply spanning, glued thin webbed beams on pin supports in accordance with BS EN 1995-1-1:2004 to ensure compliance with EC5. This limits deflection to span/250 and assumes that all glued connections are stronger than the surrounding timber and that all timber is graded to C16 and has characteristic

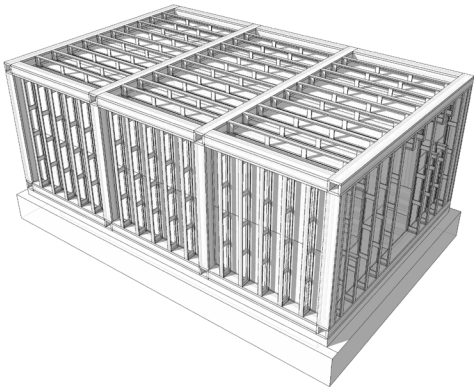
4 Cowley Timberwork, *Ty Unnos : Prototype Beam Test* (Lincoln: Cowley Timberwork, 2007), p. 1.



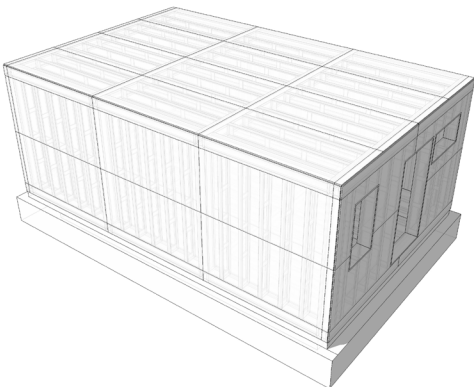
a) Post and beam frame of Sitka Spruce box sections arranged at centres according to structural efficiency. 'Portal' span the width of the volume, with edge beams simply spanning between.



b) Sitka Spruce ladder beams span between post and beam frame elements, vertically in walls and longitudinally, ie between 'portal' frames, in the ground and intermediary floors.



c) Ladder beams and frame are lined internally with OSB to provide racking resistance.



d) Ladder beams and frame are then lined externally with OSB to provide racking resistance.

Figure 6.12: Structural arrangement and assembly sequence of the Elements Europe Modular volumetric system.

Loaded Width (m)	220x220x20 Beam		220x220x40 Beam		220x280x40 Beam	
	Maximum Span (m)	Deflection (mm)	Maximum Span (m)	Deflection (mm)	Maximum Span (m)	Deflection (mm)
1.5	3.6 (M)	10.5	4.7 (δ)	18.3	5.6 (M)	20.1
2.4	2.7 (V)	6.1	3.8 (M)	12.9	4.4 (M)	13.0
3.6	1.9 (V)	2.1	3.1 (M)	8.9	3.6 (M)	9.0
4.5	1.4 (V)	1.2	2.6 (V)	6.3	3.2 (M)	7.4

Table 6.2: Results for box beams subject to domestic floor loading
() - Limiting strength properties
(M) - Moment
(V) - Shear
(δ) - Deflection
Source : Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 18.

values of shear and stiffness.⁵ Table 6.2 shows the results of this analysis when domestic loading is applied to three beam sections;

- 220x220 with 20mm thick walls,
- 220x220 with 40mm thick walls,
- 220x280 with 40mm thick walls.

The conclusions as drawn by Burroughs are;⁶

- Both the moment and shear capacities increase as section size increases,
- As web thickness doubles shear capacity approximately doubles,
- As section depth increases the moment capacity increases dramatically
- The analysis shows that the governing factor changes as spans increases with shear determining heavily loaded short spans, moment in medium spans and deflection in long lightly loaded spans.

Following this assessment Burroughs advised that the box beams as analysed, specifically the 220x220x40mm and 220x280x40mm, are structurally suitable and could produce spans appropriate to domestic use.⁷

TY UNNOS MODULAR

In Spring 2008, work began with Elements Europe on the development of a volumetric construction system using a primary structure of Sitka Spruce box sections and a secondary structure of Sitka Spruce based ladder beams.

Working with KJJ and Burroughs, Elements Europe resolved to concentrate on a 210x210mm box section constructed of four solid section timbers, finished to an approximate thickness of 40mm. Based on these dimensions, floor, wall and roof beams could be given the same specification to achieve the desired spans, and provide a suitable insulation depth to achieve a Code 3 to 4 thermal performance specification.

5 Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 11.
6 Ibid., pp. 27-28.
7 Ibid., p. 28.

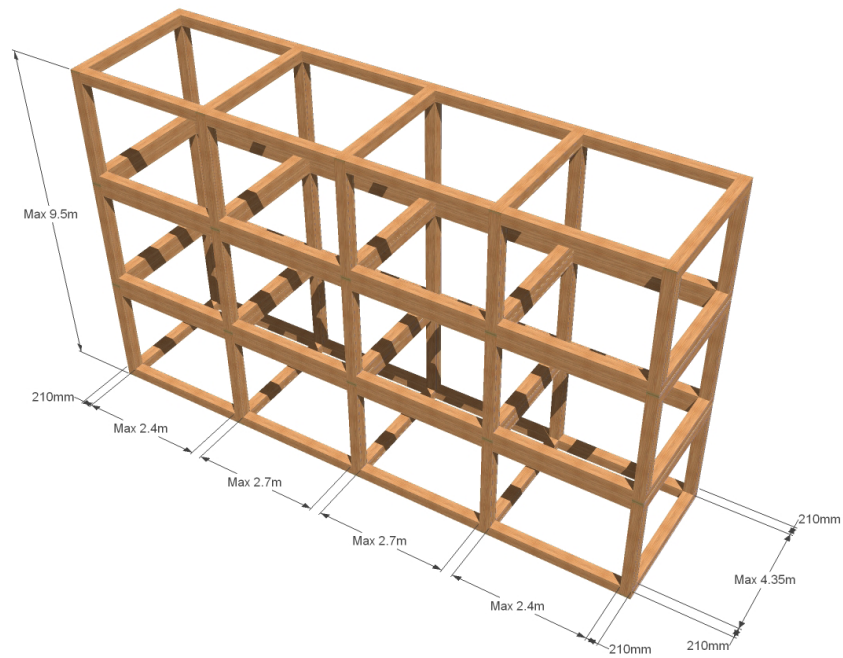


Figure 6.13: Limiting dimensions for Ty Unnos post and beam frames
Source : Burroughs, *Ty Unnos Component Toolkit*, 1st edn (Cardiff: Burroughs, 2009), p. 1.

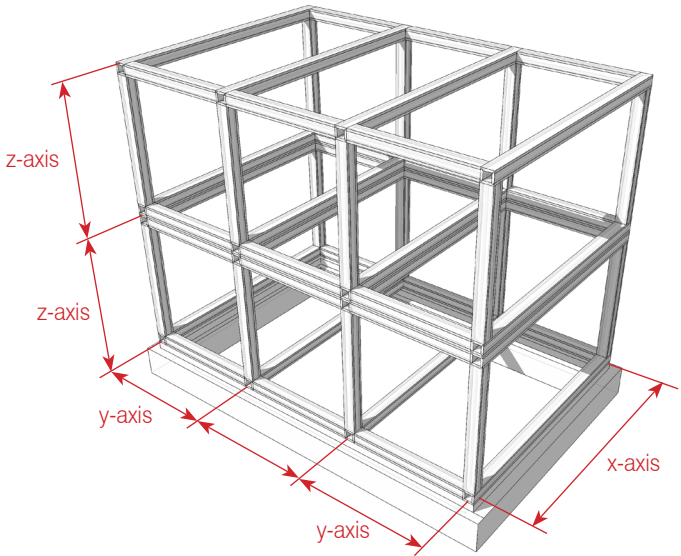
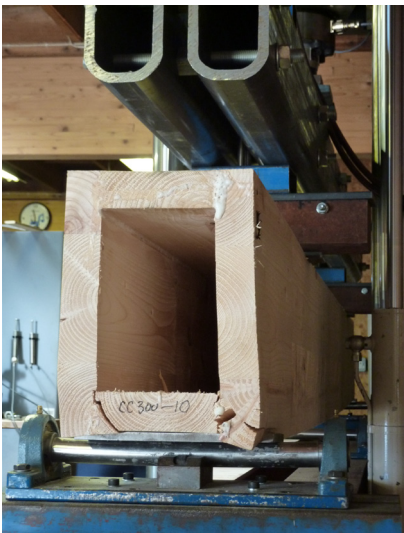
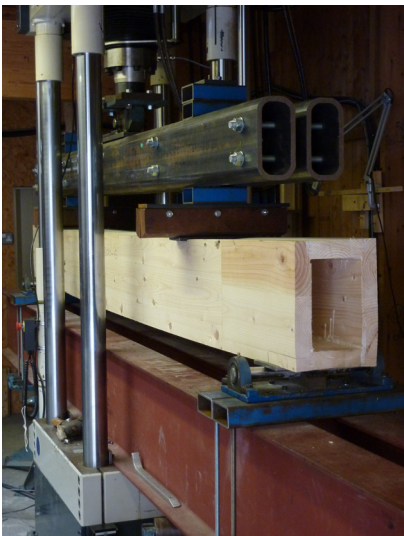


Figure 6.17: Structural arrangement of a post and beam frame

With frames at 2.9m centres a maximum span between primary columns would be 3.45m. This was not considered sufficient for the organisation of volumetric units. Burroughs therefore developed a proposal which would take advantage of the additional structural capacity provided by applying 18mm OSB to the top and bottom of each beam as floor or roof deck and ceiling. The affect of the increased effective flange of each beam enabled an increase of the maximum span to 4.35m between columns, for frames centred at 2.9m in the central bays of a framework and 2.6m centres in the end bays of the structure, see Figure 6.13. An increase in loaded width to 3.2m centres would result in a decreased maximum span to 3.7m.⁸ Based on this arrangement of box sections, the volumetric system proposed by Elements Europe received ETA certification for structures up to 3 storeys.

FURTHER TESTING

Following the conclusion of testing on the original box section geometry, a number of further structural tests have been performed on a range of box section sizes. The purpose of this round of testing has been to develop a range of test data to enable the extrapolation of structural calculations to support a range of box beam depths between 200-400mm. This testing has subsequently been extended to include all requirements for the individual ETA certification of the box beam section. It is intended that this certification will be completed in the summer of 2011.



OPPOSITE PAGE

- Figure 6.14: 400 x 210mm Box beam in 4 point loading test rig.
Figure 6.15: Box beam displaying deflection.
Figure 6.16: Close up of failure originating in the corner joints of the lower flange.

Tables 6.3 and 6.4, produced by Burroughs provide an overview of the respective permissible spans of beams under domestic floor loads and roof loads when positioned at 3m centres.

Depth / Width	150mm	200mm	250mm	300mm
200	2.75 m	3.13 m	3.46 m	3.76 m
250	3.27 m	3.68 m	4.05 m	4.39 m
300	3.78 m	4.22 m	4.62 m	4.98 m
350	4.28 m	4.74 m	5.17 m	5.56 m
400	4.77 m	5.26 m	5.7 m	6.11 m

Table 6.3: Allowable Spans for Alternative Box Beam Dimensions for Domestic Floor Loads
Source : Burroughs, *Ty Unnos Component Toolkit*, 2nd edn (Cardiff: Burroughs, 2011), p. 3.

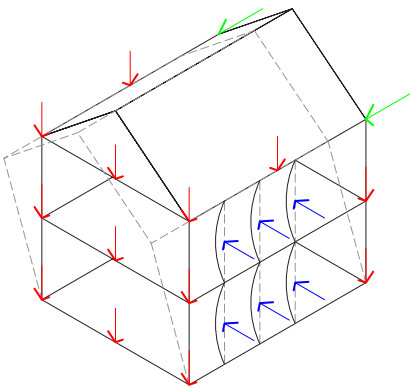
Depth / Width	150mm	200mm	250mm	300mm
200	3.14 m	3.56 m	3.93 m	4.15 m
250	3.73 m	4.2 m	4.62 m	5.01 m
300	4.31 m	4.81 m	5.26 m	5.68 m
350	4.88 m	5.41 m	5.89 m	6.34 m
400	5.44 m	5.99 m	6.5 m	6.97 m

Table 6.4: Allowable Spans for Alternative Box Beam Dimensions for Roof Loads
Source : Burroughs, *Ty Unnos Component Toolkit*, 2nd edn (Cardiff: Burroughs, 2011), p. 3.

6.02.2 FRAME RACKING AND ARRANGEMENT

In addition to supporting vertical loads, the primary structural elements must combine into 3 dimensional frames to perform two further structural functions; resistance to deformation by horizontal loading in their plane; and resistance to wind loading perpendicular to their plane, see Figure 6.18.

The feasibility study proposed an arrangement of structurally autonomous pavilions with columns positioned in each corner, connected by beams in the floor and roof planes to create portalised frames, with infill panels spanning between, see figure 6.19.



- Resistance to deformation by horizontal loading in their plane
- Support of vertical loading
- Resistance to wind loading perpendicular to their plane

Figure 6.18: Dead and live loads exerted on a typical multi storey construction.

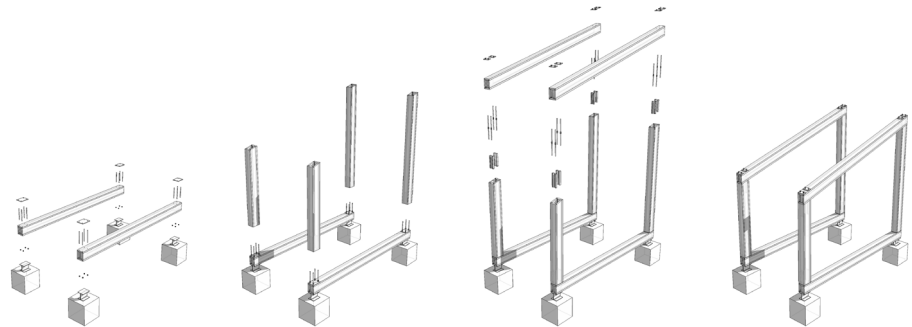


Figure 6.19: Proposed portal frame arrangement.

This theoretical organisation was employed for initial physical testing by Cowley Timberwork. The physical test was designed to replicate the potential wind loading that could be experienced on a single storey structure and measure the response in terms of deflection caused by rotation or slip in the joints or deflection in the columns. Employing 270 x 210mm Sitka Spruce box sections, the portal frame designed for testing, was connected in each corner using resin bonded threaded rods installed into the uprights and bolted through the horizontal beams. It was arranged as a single storey mono pitched frame with a maximum internal span, ie from the inside face of each column, of 4.8m. The testing process, illustrated in Figure 6.22 was performed as follows;

- The portal frame was laid horizontally, and fixed to steel plates securely anchored into the concrete floor slab using a steel I section junction.
- A hydraulic ram is also restrained against an anchor bolted angle with the arm positioned against the highest point of the vertical section.
- The hydraulic ram is gradually engaged, applying a force to the extremity of the portal frame whilst recording the resultant deflection.

Under a horizontal load of 950kg the portal frame displayed a deflection of 22mm.

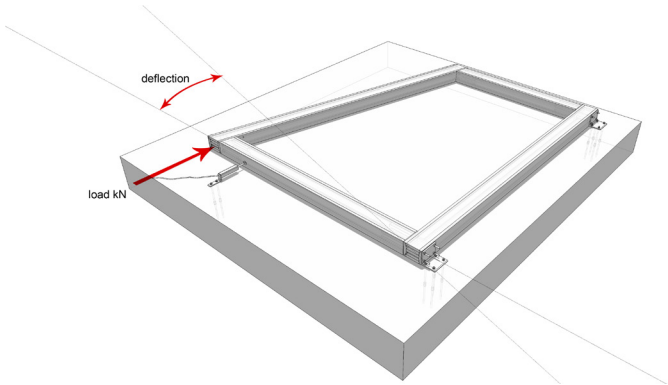


Figure 6.23: Portal frame arrangement employed by Cowley Timberwork to test deflection under horizontal loading, ie wind loads.

The physical test was replicated by Burroughs using CADs Analysis software to model the exact frame dimensions, section sizes and loading. The analysis found the calculated deflection under 950kg of horizontal load to be 19mm.⁹ This includes a calculation of joint slip and shear deflection. Although the results are supportive, the study did not provide a large enough sample of physical testing results to be conclusive.¹⁰

The second stage of analytical modelling performed by Burroughs considered a standard rectangular portal frame and calculated the frame centres required to resist horizontal wind loading for one, two and three storeys based on the alternative box section dimensions calculated previously. See Table 6.5

9 Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 21.
10 Ibid., p.31.

OPPOSITE PAGE

Figure 6.20: Mono pitch Sitka Spruce portal frame prepared for testing.
Figure 6.21: Box beam displaying deflection.
Figure 6.22: Close up of threaded rod junction showing steel compression plate, additional timber compression strut, and I section foundation junction.

Storeys	220x220x20 Beam		220x220x40 Beam		220x280x40 Beam	
	Maximum Centres (m)	Deflection (mm)	Maximum Centres (m)	Deflection (mm)	Maximum Centres (m)	Deflection (mm)
1	3.6 (δ)	9.6	5.5 (δ)	9.6	8.8 (M)	8.1
2	1.3 (δ)	19.2	2.0 (δ)	16.2	3.8 (M)	19.0
3	0.7 (δ)	28.8	1.1 (δ)	28.8	2.1 (δ)	28.8

Table 6.5: Results for a 3m wide by 2.4m high portal frame under typical UK wind loading and floor loadings.
() - Limiting strength properties
(M) - Moment
(V) - Shear
(δ) - Deflection

Source : Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 21.

The conclusions presented by Burroughs include;

- The required frame centres decrease as the number of storeys increase,
- As the width of the frame increases the capacity becomes more dependent on deflection,
- When two frames act together, ie a double bay, the capacity is more than doubled, and frame centres can be increased.

Generally the analysis finds that the portal structure can perform well at reasonable frame centres up to two storeys.¹¹

Following continued development of the box section frame structure in conjunction with Elements Europe and the TSB SHSS house project, Burroughs proposed the conclusion that the use of structural ‘portal’ type frames would not enable a wide application for structures over single storey. Specifically this was due to;

- The geometry of designs proposed in the Pattern Book study are typically long, thin buildings due to the limited maximum spans of floor beams. They are also often considered as detached units, with tall and wide elevations. This type of geometry encourages very high wind loadings.
- Eurocode 5 provides a different requirement for racking resistance in timber frame construction, which is likely to result in a dramatic change to current practice in open and closed panel timber structures.
- Many areas of Wales, specifically rural Wales, will pose climatic conditions with wind loadings that will be considerably higher than those proposed through generic analysis.
- In order to meet the spatial demands of affordable housing, box beams and ladder beams are likely to be employed at their maximum spans and centres. Therefore there will be limited reserves of structural capacity within the components to allow for changeable loadings such as geographically determined wind loadings.

Alternative forms of diaphragm, specifically board products such as Oriented

11 Ibid., p. 21.

S t a b i l i t y System	Drawing No	Description	Un-factored Load Capacity (kN)
S t a n d a r d Diaphragms	Ssk 002 (Fig. 6.25)	18mm OSB attached to the frame with screws at 100mm centres on both faces.	15.76
Diaphragms with hardwood	Ssk 003 (Fig. 6.26)	Timber behind standard diaphragms receiving screws is replaced with hardwood such as British Oak.	18.53
Single Sided Diaphragms	Ssk 004 (Fig. 6.28)	As standard diaphragm but with OSB on one side of the frame only.	7.88
Steel Frame	Ssk 005 (Fig. 6.27)	A steel frame made up of 100 x 10mm sections bolted to the timber frame.	50.00
Bolted Cross Bracing (single shear)	Ssk 006 (Fig. 6.29)	Steel cross braced flats bolted to the timber frame at the nodes with single shear connections.	15.98
Bolted Cross Bracing (double shear)	Ssk 007 (Fig. 6.30)	Steel cross braced flats bolted to the timber frame at the nodes with double shear connections	31.96

Table 6.6: Results of a feasibility study into alternative structural bracing systems based on a typical building form.
Source : Thomas Martin, (thomas.martin@burroughs.co.uk). (2010, November 18). – 2250 - *Steel crossbracing feasibility study - comparisons of options*. Email to D.Jenkins (davidj@coedcymru.org.uk).

Strand Board (OSB) dramatically improve the lateral load bearing performance of the proposed structures, and would therefore reduce the demand placed on the primary structural elements. OSB sheathing boards are often employed as the sole provider of structural stability in timber frame panel systems.

Guidance from Burroughs therefore proposed the application of 18mm OSB to the interior and exterior of the box section frame. With appropriate fixings around the perimeter of each board creating a direct connection between the OSB and the box section frame, the OSB can provide capacity for all long term lateral stability. The box section frame and its connections can therefore be employed to simply provide temporary stability during construction.

This proposal was applied by Burroughs to the design of the Ty Unnos Modular system. Applied to a 9.5m high structure, including roof, a 4.8m long building would typically require two 1.2x2.4m panels on each floor level. For a 9.5m long building, 4 panels per floor would be required.¹²

DIAPHRAGM STUDY

Following analytical and physical modelling, and its application in the Elements Europe Modular system, diaphragm panels of OSB were employed in the detailed design of the initial prototypical studies, the Welsh Folklife Pavilion and the Welsh Passive House. These will be discussed in further detail in Chapter 8.0. Through prototyping and the detailed design and construction of these studies, a number of significant factors arose from the reliance on OSB for the provision of racking resistance;

- 1. Local sources of OSB are not available thus challenging the primary objective of adding value to local timber resources.
- 2. In order to realise the structural capacity of OSB there are significant restrictions placed on the design of prefabricated infill panels, and their relationship with the design of domestic scale spaces.

In addition to these restrictive factors it was considered that a spruce based panel, providing both structure and sheathing, could offer a solution to these tensions if it was capable of resolving the essential structural functions. The design of spruce based panels will be discussed in detail later in this section. However, following guidance from Burroughs, and a number of initial trials, it was concluded that a simply jointed panel sheathed in small sections of tongue and groove Sitka Spruce would not provide a suitable capacity as diaphragm panels without a secondary form of bracing.

Burroughs were therefore asked to perform a feasibility study, in order to propose and consider a range of alternative solutions to provide structural bracing. The study employed the form and structural organisation of the Welsh Passive House at Ebbw Vale in order to compare alternative systems in a realistic context.

12 Burroughs, *Ty Unnos Component Toolkit*, 1st Edn, p. 4.

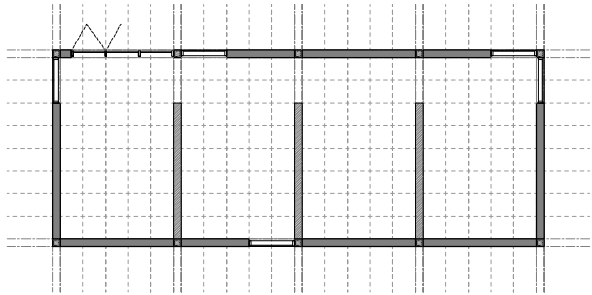


Figure 6.24: Linear plan form based on the Welsh Passive House arrangement

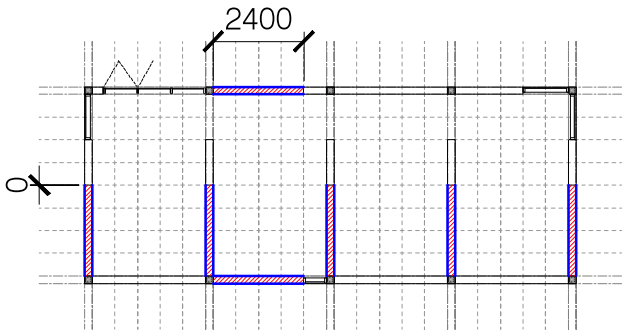


Figure 6.25: 18mm OSB attached to the internal and external faces of the frame with screws at 100mm centres.

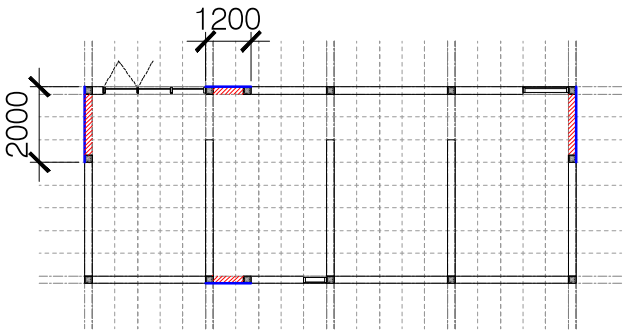


Figure 6.27: A steel frame made up of 100 x 10mm sections is bolted directly to the timber frame.

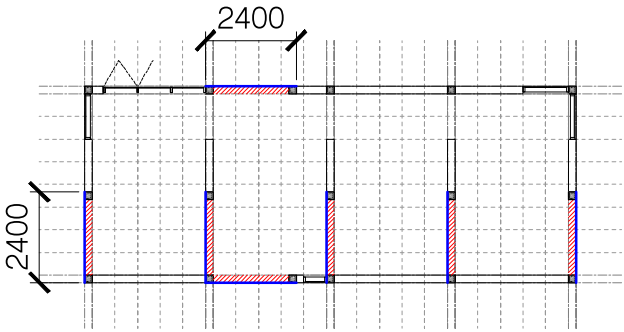


Figure 6.29: Steel cross braced flats bolted to the timber frame at the nodes with single shear connections.

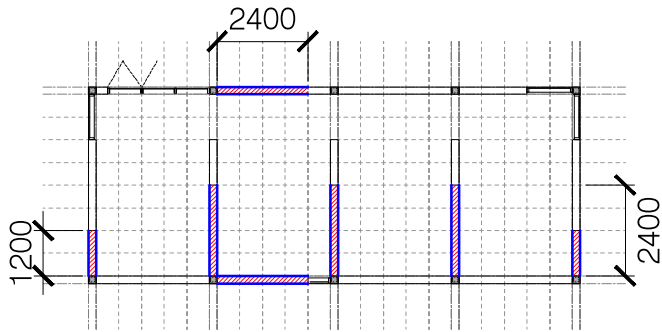


Figure 6.26: The timber behind standard diaphragms is replaced with hardwood such as British Oak to receive fixings.

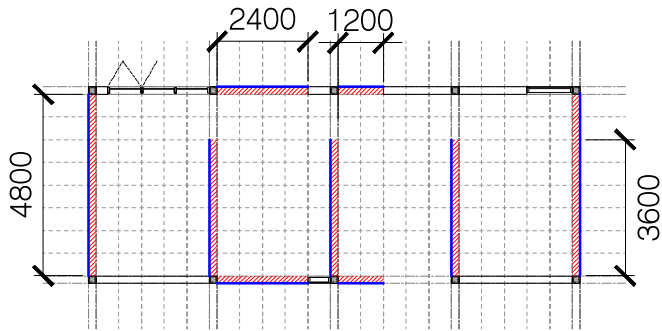


Figure 6.28: As standard diaphragm but with 18mm OSB fixed to one side of the frame only.

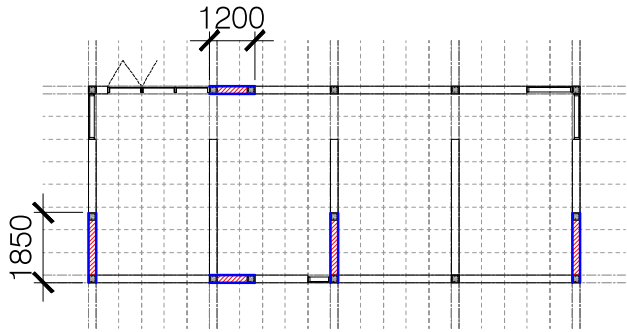


Figure 6.30: Steel cross braced flats bolted to the timber frame at the nodes with double shear connections

Five alternative racking systems were compared as described in Table 6.6. Figures 6.24 - 6.30 show the required areas of each system to provide sufficient stability for a typical wind loading scenario. When compared with the load capacity provided by a layer of 18mm OSB suitably fixed to both the interior and exterior faces of the box section frame, the study found that three arrangements of steel bracing could provide at least the same capacity.

The alternative bracing options assessed within the feasibility study display a number of opportunities for reducing the reliance on OSB panels. The stability provided by steel bracing offers the potential to remove racking performance from the infill panel design generally. Bracing could instead be applied to the exterior of the constructed thermal envelope where required, enabling a much greater freedom over the design of infill panels and potentially the use of a non-structural Spruce based infill panel. Although further work is required to fully consider the cost and detailing implications, the feasibility study concluded that steel bracing could provide a suitable alternative to OSB panels.¹³

6.02.3 FRAME CONNECTORS

The junctions of traditional post and beam frames are shaped out of large sections of solid material to create joints such as mortise and tenons, or dovetail joints, with pegs and wedges inserted to hold joints in place. Although the proposed box section frame shares much in common with traditional solid section post and beam frames, the hollow nature of the box beam make the transfer of traditional jointing methods and modern fixings such as flitch plates problematic.

Initially the proposed portal frame arrangement demanded a relatively simple 2 dimensional junction providing direct connection between floor beam and columns, and columns to roof beams, to form a 'portal' frame, see Figure 6.32. As the project progressed it was proposed that the inclusion of edge beams spanning between 'portal' frames at floor beam intersections and eaves, see Figure 6.31 (e - f), would simplify the design of infill and racking panels. In this arrangement of primary frames and edge beams, all floor and roof loads are carried by the primary frames connected using 2 dimensional junctions. Edge beams, connected to the primary frames using simple shear connections, are therefore employed solely for the support of external walls.

THREADED ROD CONNECTORS

Drawing on the experience of Cowley Timberwork, the box section portal frame was initially designed to utilise a threaded rod and nut connection to joint floor beams to columns. The system employs slow setting epoxy resin to glue four

13 Martin, T. (thomas.martin@burroughs.co.uk). (2010, November 18). – 2250 - Steel crossbracing feasibility study - comparisons of options. Email to D.Jenkins (davidj@coedcymru.org.uk).

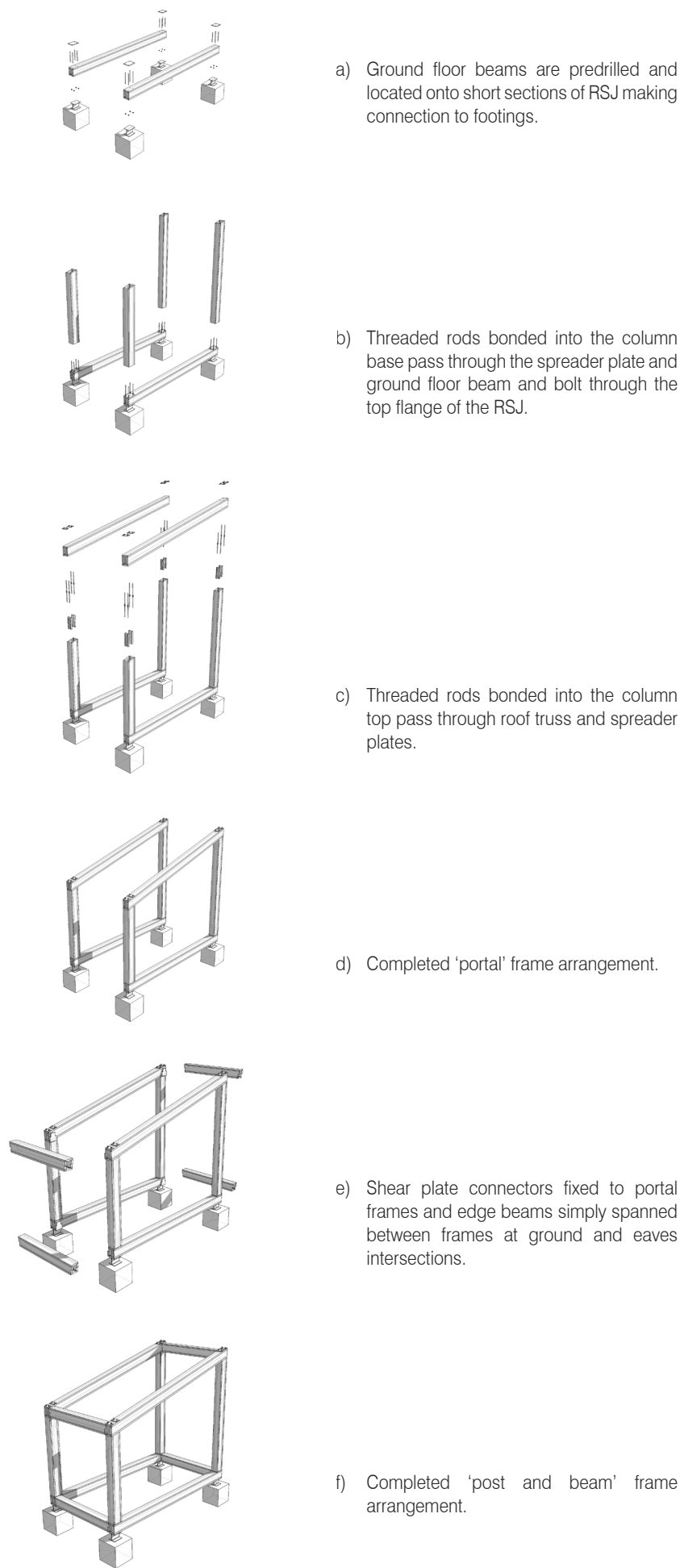


Figure 6.31: Assembly process of portal and post and beam frame using threaded rod connections.

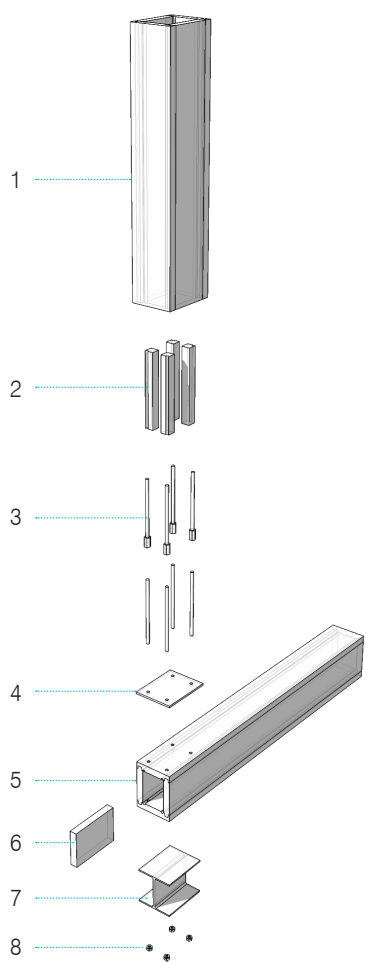


Figure 6.32: Threaded rod connection detail

1. box section column
2. timber battens providing localised thickening of box section corners
3. threaded rod resin bonded into column base
4. steel spreader plate
5. ground floor box section beam
6. localised strengthening timber
7. RSJ foundation connector
8. Anchor bolts into foundations.

600mm lengths of M16 threaded rods into the end grain of the box beam columns. These rods pass through a steel bearing plate between column and beam and vertically through drilled holes in the floor and roof beam. The joint is completed by oversized washers and nuts applied to the underside of the floor beam, and the top edge of the roof beam, see Figure 6.32.

In order to provide connection between the primary frame and foundation, Cowley Timberwork have combined this moment connection with a steel shoe detail. Consisting a short section of RSJ positioned at the corner joints of the frame. It is proposed that this section is prefixed to the portal frame, acting to distribute the loads placed on the Spruce beam by the threaded connector rods. The section is then bolted down to the foundations when located in to place.

Table 6.7 shows the results of analysis performed by Burroughs on the proposed threaded rod connection.

Storeys	220x220x20 Beam	220x220x40 Beam	220x280x40 Beam
	Maximum Centres With 350mm Bolt Embedment (m)	Maximum Centres With 625mm Bolt Embedment (m)	Maximum Centres With 725mm Bolt Embedment (m)
1	3.6 (Frame)	3.8 (Connection)	4.6 (Connection)
2	1.3 (Frame)	1.7 (Connection)	2.0 (Connection)
3	0.7 (Frame)	0.99 (Connection)	1.2 (Connection)

Table 6.7: Results for portal frames with bolted connections
Source : Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 22.

The analysis considers the potential for;¹⁴

- Crushing of the timber in the compression zone of the joint, ie above and below the spreader plate, and below the top flange of the box beam,
- Pull out or tensile strength of the steel rods bonded in to Sitka Spruce end grain,

when maximum moments and axial loads are applied to the junction.

The results of the analysis show that the connection becomes the limiting factor of frame performance for all but the 220x220x20mm box section structure. To put in to context, a single storey building constructed of 220x220x40mm box sections would have the maximum frame centres reduced from 5.5m to 3.8m with the application of these junctions whilst a two storey structure constructed of 280x220x40mm box sections will be restricted from 3.8m to 2.0m centres.

In developing this analysis Burroughs and Cowley Timberwork have employed a number of design adaptations to improve the potential capacity of the joint. Crushing of the compression zone is a limiting factor therefore additional timber



Figure 6.33: Threaded rod connection manufactured by Cowley Timberwork showing spreader plate, foundation connection and additional compression timber.

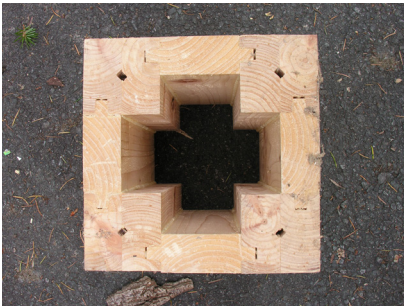


Figure 6.34: 2 70x35mm sections are laminated and pilot drilled, and laminated with web timbers to form box section.

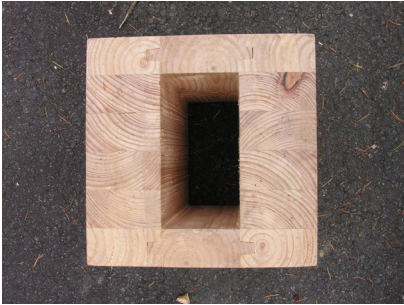


Figure 6.35: 6 75x35mm sections laminated to form flanges with 75x35mm profiled web timbers



Figure 6.36: 6 50x35mm sections are laminated along the face with 125x35mm profiled web timbers

has been integrated locally in the box section, see Figure 6.33.¹⁵ However to improve capacity significantly this has typically resulted in an effectively solid end section to each beam. In addition the length of threaded rod has been increased to improve the axial capacity in line with the improved compression capacity, with rods embedded up to 725mm into the 280x220mm section.

Despite these alterations Burroughs concludes that the capacity of the threaded rod connection is a limiting factor for frames and for frames of two storeys or more, the required frame centres are impractical for a domestic application.¹⁶

In addition to this performance conclusion, the manufacture of the threaded rod junction posed a number of challenges;

- The 37mm thickness of box section walls was found to be too thin for the bonding in of threaded rods therefore localised thickening was required at corners in the form of a square section of 47x47mm spruce.
- The gluing and fixing of square sections into the box beam hollow was time consuming and awkward, as sections could not be successfully clamped into the depth of the box section.
- The drilling of 15mm holes to receive threaded rods could not be achieved accurately using hand held drills despite the prepared pilot hole and suitable machinery ie a horizontal boring machine was not available.

A number of alternative box section geometries were therefore considered to make this manufacturing process more efficient, see Figures 6.34 - 6.36. These sections are made up from multiple small standard sections of timber, preformed into individual laminated sections using sash or panel press clamps prior to processing to form the box section geometry. Although the laminations were generally of a high quality the additional processing required a considerably higher input of labour and a higher quality of timber entering into the production.

The threaded rod connection as designed by Cowley Timberwork has been employed in the construction of the Ebbw Vale Environmental Resource Centre and will be discussed in further detail in Section 8.03.

CONNECTORS_ 'L' SHAPED SOLID SPRUCE OR PLYWOOD

The geometry of the hollow box section frame suggests that a moment connector could be designed to be accommodated within the hollow of the box. Initial studies considered two forms of connector; a fabricated steel hollow section junction, with arms extended in multiple directions to carry multiple frame elements, and a rigid laminated timber or plywood 'L' shaped connector, with steel reinforcement if necessary. See Figure 6.37.

15 Ibid., p. 32.

16 Ibid., p.32.

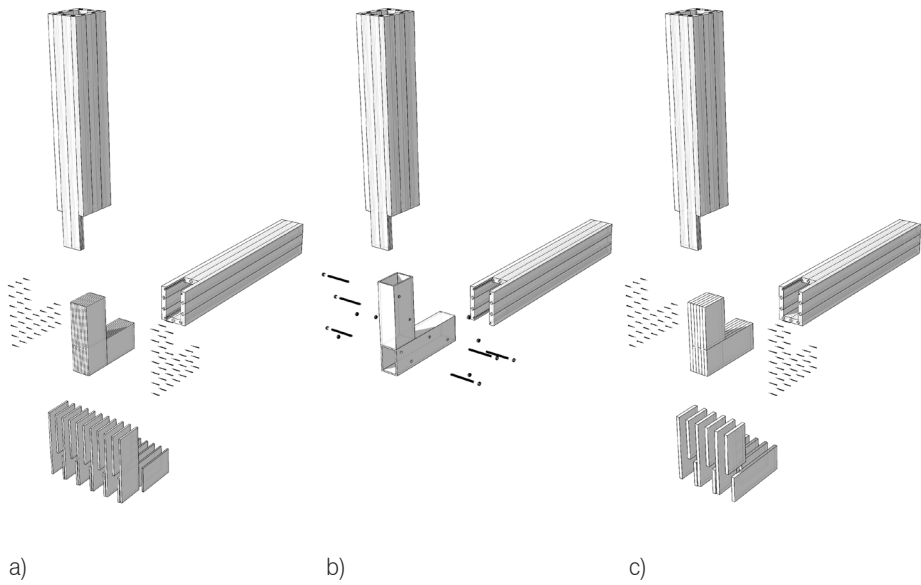


Figure 6.37: Alternative elbow connector types; a) Solid connector of 11 plywood laminations, b) rectangular hollow section welded at junction, c) Solid connector 6 spruce laminations

As a 2 dimensional 'portal' frame it was deemed that a solid connector operating in just the portal frame axis, ie connecting primary floor beam to column, would be sufficient, with secondary edge beams simply spanning between the primary 'portal' frames. The solid timber connector therefore offered a simple solution to the connection between floor beam and column, and could be easily adapted to permit alternative angles in the column to roof beam junction at eaves level. The geometry of this connector also enabled the further use of standard section Sitka Spruce, employing sections of 47x150mm machined to a standard thickness and laminated together in a finger joint arrangement to form an 'L' section.

- 1. box section column
- 2. edge 'spanning' box beam
- 3. solid elbow connector
- 4. primary ground floor box beam
- 5. shear plate connector.

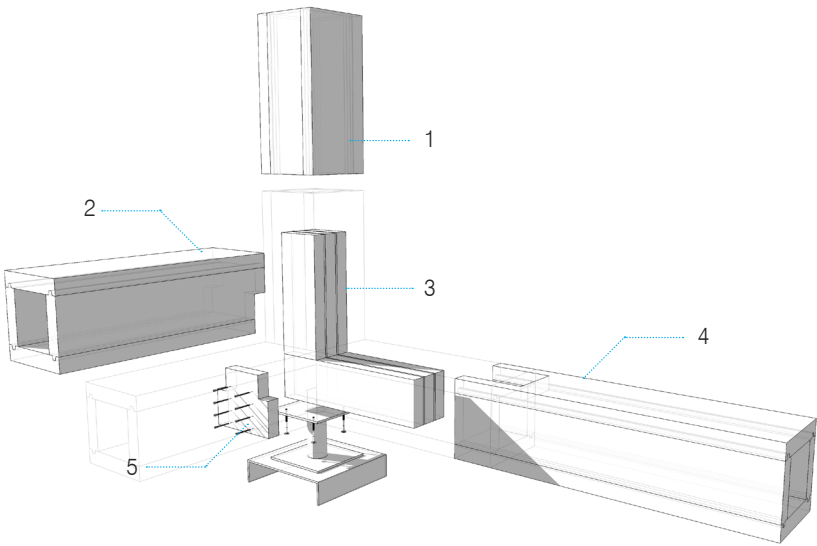


Figure 6.38: 3 dimensional junction arrangement using laminated spruce connection.

Table 6.8 shows the results of a study performed by Burroughs for the design of 'L' connectors. The assessment shows a number of connector design options for alternative box section geometries. The specification of the alternative designs have been calculated to ensure that the connector is capable of providing the full

Beam Type	'L' Piece length (mm)	Steel 'L' piece size	Timber 'L' piece size
220x220x20	200	180x180x5.0 SHS	180x180 with 3 Laminations
220x220x40	450	140x140x5.0 SHS	140x140 With 7 Laminations
220x280x40	550	200x120x5.0 RHS with 10mm packing either side	200x140 With 5 Laminations

Table 6.8: Results for elbow connections
Source : Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 24.

moment capacity required by the frame when positioned at maximum centres as set out in Table 6.7.

The initial study made the assumption that all axial loads are transferred from the frame into the connector through shear. A number of options were considered to enable this junction;

- The connector is glued into the box section hollow,
- Bolts are drilled through the full thickness of the box section and connector,
- Screws are driven through the box section webs into the connector from both sides,
- A combination of the above.

In order to test these options Burroughs designed a test which could employ a 4 point bending rig. The test consisted of two short sections of 220x220x40mm box section spliced together with a junction of either solid timber or box section steel. A number of fixing arrangements were then trialled.

	Beam Capacity		Insert Length (mm)	J o i n t moment capacity (kNm)	Applied Effects at Failure		Joint Moment Utilisation Ratio at Failure
	Moment (kNm)	Shear (kN)			Moment (kNm)	S h e a r (kN)	
TB 1	13.55	20.88	400	5.18	9.955	22.0	1.92
TB 2	16.27	24.48	800	20.11	25.45	65.0	1.266
TB 3	16.27	24.48	600	11.31	17.5	40.0	1.547

Table 6.9: Results of Flexural testing on splice connections performed by CEREА.
Source : Thomas Martin, (2010, June 22). *2227 - Rotafix Box Beam Connection Testing: Glamorgan Box Beam Testing*, Letter to D.Jenkins.

The findings of the test are displayed in Table 6.9. The test enabled Burroughs to draw the following conclusions;

- The predicted capacity of each joint was considered valid, as 95% of all joints tested would exceed the calculated characteristic value shown in the table.
- The test samples demonstrated that an increase in insert length dramatically increases the moment capacity of the joint, approximately

proportional to the square of the insert length.

- There is no significant performance difference between steel or timber inserts and there is no significant difference between glued and bolted connections.¹⁷

Burroughs therefore proposed a laminated timber ‘L’ connector consisting of 5 sections of 140x35mm section with a minimum insert length of 500mm, bonded using a polyurethane glue in a finger joint arrangement at the elbow. These joints could be combined at any angle to achieve any desired roof pitch. The proposal was successfully adopted by Elements Europe for the assembly of the primary structure of Ty Unnos Modular and has been employed in a number of demonstration assemblies. A development of this joint, which combines Sitka spruce sections with steel plates to form a bolted lamination was employed in the construction of the Welsh Folklife Festival Pavilion, and the Welsh Passive House.

SHEAR CONNECTORS

In order to connect spanning edge beams to the primary portalised structure Burroughs developed a simple shear connection which takes the form of a ‘T’ shaped timber plate, see Figure 6.40. This connection was developed primarily for the Elements Europe Modular system and was subsequently designed to work in conjunction with internal and external sheathing panels. In this arrangement very limited structural capacity is required from the junction. Through mathematical analysis the proposed connector was designed to meet the requirements of the joint as simply as possible. The design of the connector and the associated assembly processes will be considered in more detail in Chapter 8.0.

1.

2.

3.

4.
- box section column

edge ‘spanning’ box beam

primary ground floor box beam

shear plate connector.

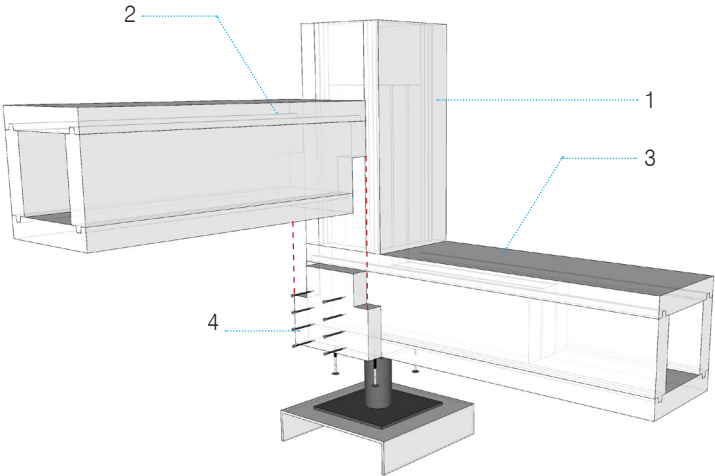


Figure 6.39: Shear plate connector making connection between ‘portal’ frame and spanning edge beams.

17 Thomas Martin, (2010, June 22). 2227 - Rotafix Box Beam Connection Testing: Glamorgan Box Beam Testing, Letter to D.Jenkins.

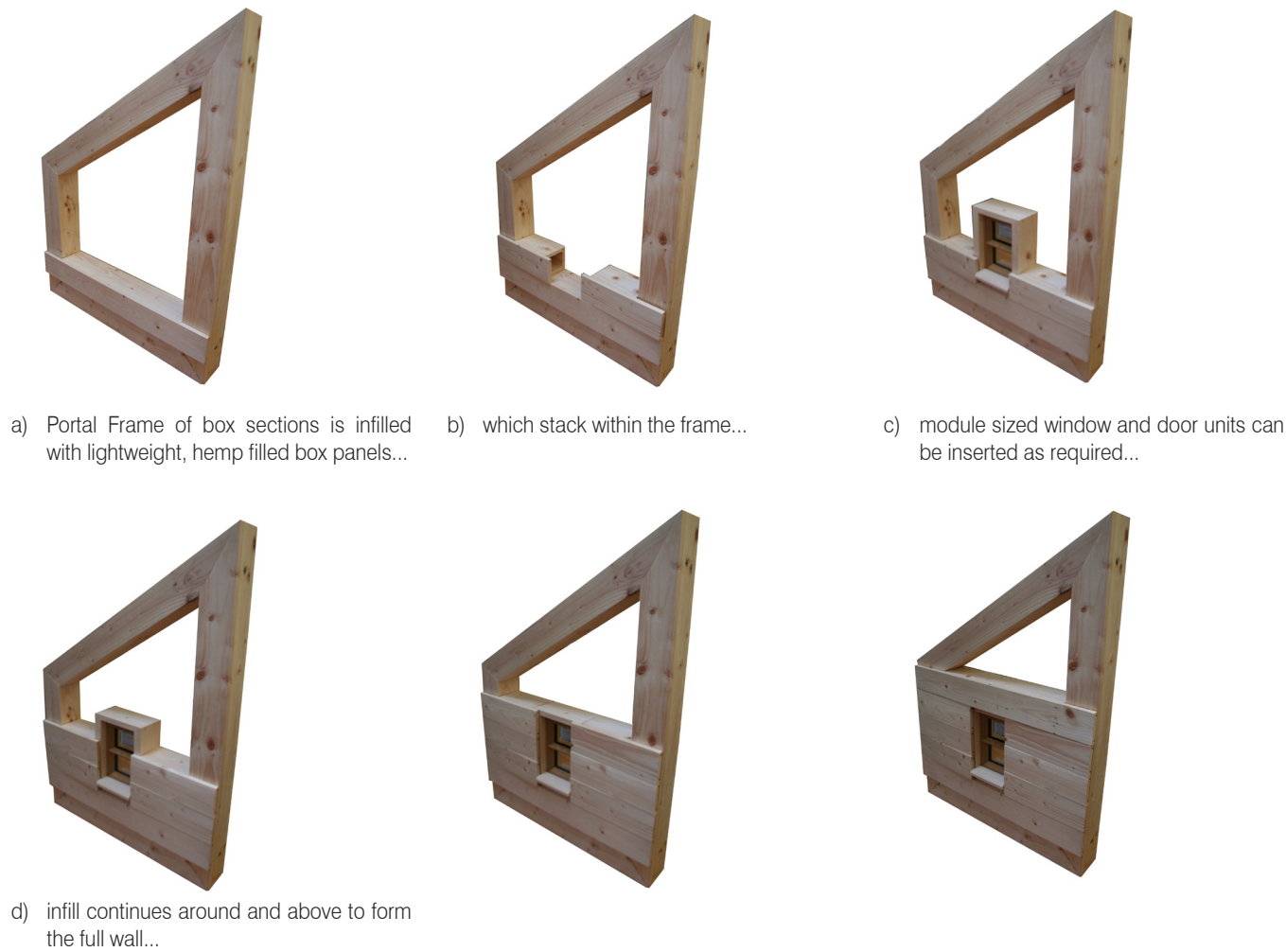


Figure 6.40: Construction sequence of box panel based construction system
Source : Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007), p. 18.

6.03 SECONDARY STRUCTURE

The development of a load bearing structural element in the form of a box section has provided an engineered homegrown component that appears to be successful and appropriate for residential applications. However it alone does not provide a whole house solution capable of successfully fulfilling the principle objectives of this study.

The feasibility study proposed a system of small scale infill components that could span between the primary load bearing structure and act as an efficient thermal container for natural insulations such as sheeps wool, hemp or recycled newspaper. Initial studies focused on a derivative of the proposed box section geometry capable of spanning between portal frames to form floors and roof decks, and stack between columns to form internal and external walls. Dimensionally coordinated door and window cassettes would integrate with wall elements to complete the thermal envelope. Figure 6.41 show a number of initial trials with the box section geometry.

The scale and complexity of assembling these early trials suggested the need for an engineered secondary structural element which could form the basis of non-loadbearing infill panel, and could act as an alternative to solid section studs or joists.

CONTRIBUTIONS TO THE DEVELOPMENT OF THE SECONDARY STRUCTURAL COMPONENTS INCLUDE;

- Consultation regarding target and realised ladder beam capacities when applied to the design of house types.
- Involvement in the iterative testing of alternative ladder beam geometries and specifications.
- Detailed design and prototyping of Type 02 ladder beam variations when applied as part of a whole house construction system, specifically focused on the junction between primary structure and infill, integration into panel design, and the design of end sections to allow trimming.
- Extensive investigations into the manufacturing process of ladder beams 01 and 02 and the development of a repetitive manufacturing process and jig for ladder beam 02.
- Review and feedback to the Project Team on the opportunities and limitations resulting from the ladder beam specification and manufacturing process.
- Review and feedback to the Project Team on the opportunities and limitations resulting from the construction/assembly process when applied to a number of prototypical studies.

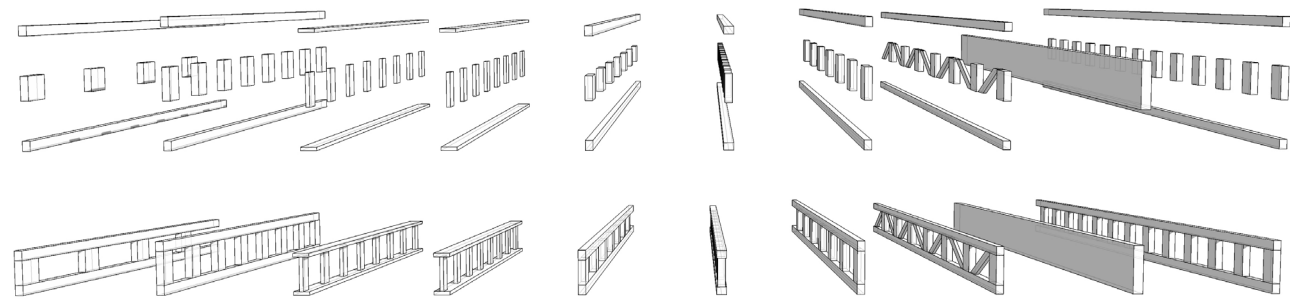


Figure 6.41: Initial ladder beam prototypes for preliminary testing by Kenton Jones Joinery.



Figure 6.42: Selection of photographs of preliminary testing on ladder beams as Kenton Jones Joinery.

Source : Burroughs, *Prototype Testing Report* (Cardiff: Burroughs, 2009), pp. 1-3.

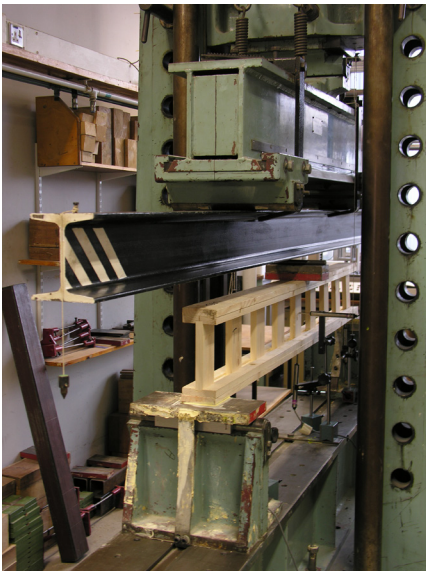


Figure 6.43: Testing arrangement at Glamorgan University.



Figure 6.44: Closeup of failure of simulated OSB flange and significant rotation of struts under loading.



Figure 6.45: Failure of glued connection caused by significant rotation of struts.

6.03.1 SECONDARY STRUCTURE_ TY UNNOS LADDER TYPE 01

Drawing on experience of trials using small section hardwoods, Coed Cymru proposed a number of beam geometries using small section Sitka spruce simply jointed with a top and bottom flange and short vertical webs evenly spaced to create a ladder type arrangement.

Due to the number of design factors within the proposed arrangement that can affect stiffness, the testing and development of ladder beams has followed an extensive cyclical process. A number of arrangements are produced, typically by Coed Cymru under guidance from Burroughs, and tested to provide an assessment of stiffness. The most promising arrangements are then taken forward for further development. In the case of Ladder Type 01, testing was performed in four stages;

TEST 1

An initial range of seven prototype ladder beams were produced by Coed Cymru and Kenton Jones to test a stiffness value and the failure mechanism.

Ten beams were tested in total, shown in Figure 6.42. Each ladder was designed with the basic principal of a top and bottom flange of solid section Spruce with solid timber rungs spaced at varying distances to form a web. These rungs were either glued, screwed or both and in some arrangements a channel routed into the top and bottom boom provides a housing for gluing.

Initial testing of prototypes carried out at KJJ in Feb 2009 utilised a simple test arrangement designed by Burroughs. The ladder beams were supported off the ground at each end with a car jack positioned at the centre of the beam. A vertical force was applied by the car jack and the resultant load measured on a standard weighing scales positioned under the car jack, see Figure 6.43.¹⁸

Each beam was first loaded to 100kg and the resultant deflection recorded using a ruler. Each beam was then loaded to failure and the mode of failure assessed. Two distinct failure modes were recorded;

- Failure in the tension zone of the boom to strut connection
- Tensile failure in the top boom

TEST 2

A second range of prototypes were then tested by the Centre for Research, Engineering and Environment Applications (CEREA) at Glamorgan University. Flexural testing was performed on 7 beam geometries employing three alternative types of connection between web and flange;

- PVA glued connection in a 5mm trough were applied to test beams 1,3,5,

and 6.

- Screwed connections with 2 No 40mm screws and PVA glue were used for tests 2 and 7.
- PVA glued connection in a 20mm trough was used for test 4.

A secondary flange was applied to the top and bottom of each ladder beam, except test 4, in order to replicate the additional capacity presented by the application of 18mm OSB to the top and bottom of each ladder.¹⁹

A 3 point load cell was used to provide incremental load cycles with deflection measured by transducers at support points and at mid span. Each beam was loaded incrementally until deflection became significantly non-linear. The applied load was then held for 5 minutes, and removed and the retained deflection recorded.²⁰ This cycle was repeated three times and then beams were reloaded to failure. Failure loads ranged between 1.75kN and 3.2kN.

TEST 3

The results provided by CEREA were analysed by Burroughs and a further set of geometries were recommended for testing. A simpler test process was performed by KJJ on five revised beam geometries to test a simple pass/fail against four criteria as shown in Table 6.10.

	In service deflection limit under SLS load (mm)	Test deflection limit at 140 kg (mm)	Rung Moment In Service Under SLS Load (kNm)	Point Load Required For 2 x SLS Rung Moment (kN)
2.5 m	10	21.5	0.41	2.74
3.0 m	12	12.4	0.52	3.46
3.5 m	14	7.8	0.63	4.17

Table of test criteria

Table 6.10: Calculated Test Criteria for Ladder Beam test 3
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), p. 8.

- Test 1 applied three paving slabs with a total weight of 140kg at mid span, with the resultant deflection measured with each slab added and subsequently removed.
- Test 2 applied six paving slabs with a total weight of 280kg by forklift with the resultant deflection recorded.
- Test 3 applied a central load of 25 slabs, with a total weight of 1170kg and the failure mechanism of the beam recorded.

The Pass/ fail results for each beam against the essential criteria are shown in Table 6.13.



Figure 6.46: Test 3 performed at Kenton Jones Joinery.
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), pp. 7-8.

¹⁹ Ibid., p. 4.

²⁰ Ibid., p. 4.

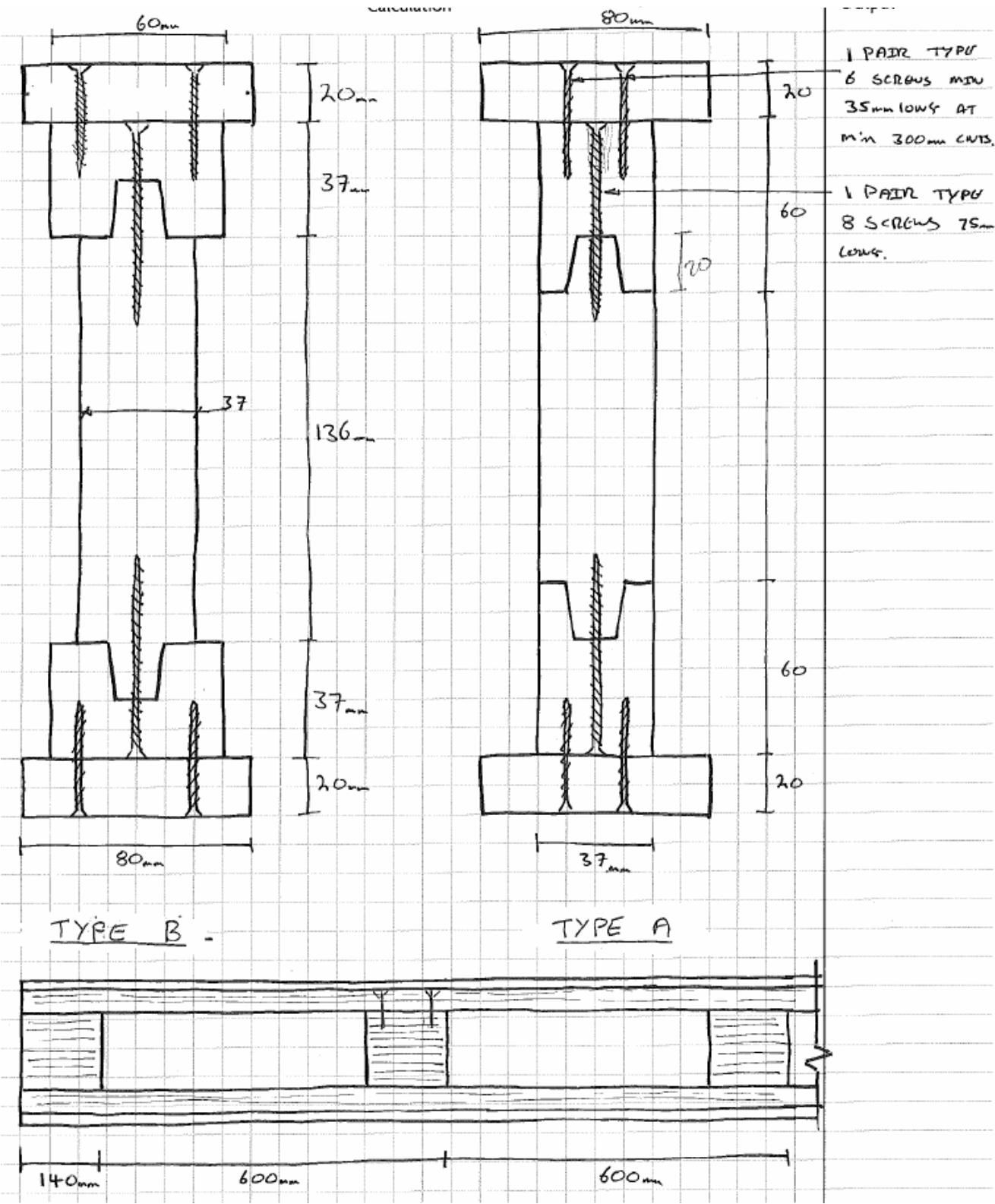


Figure 6.47: Geometry of specimens for final testing.
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), p. 11.

	Deflection under 140kg (mm)	Deflection under 280kg (mm)	Significant failure under 280 kg	Max allowable span from deflection limit (m)	Max allowable span from ultimate limit (m)	Stiffness (kNmm ² x10 ⁷)
Test 1	8.0	16.0	No	3.0	2.5	9.84
Test 2	8.5	19.0	No	3.0	2.5	9.26
Test 3	8.5	19.0	No	3.0	2.5	9.26
Test 4	9.5	37.0	Yes	3.0	None	8.29
Test 5	11.5	61.0	Yes	3.0	None	6.85

Table 6.11: Results for Ladder Beam test 3
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), p. 9.

TEST 4

The final stage of testing for Ty Unnos Ladder Beam Type 01 was performed by CERE at Glamorgan University in April 2009. The test used 5 samples of two different beam geometries, as shown in Figure 6.48.

Beams were loaded in 4 point bending using a load cell with transducers recording vertical deflection. The test samples were once again loaded incrementally until a non linear response is witnessed and then held under load for 5 minutes before release. This process was repeated three times on each sample and then loaded to failure.²¹

The test designed by Burroughs enabled the assessment of beams against two performance factors equivalent to the criteria set out in BS5268-2;

- Ultimate load bearing capacity: the ultimate load attained should be twice the service load. At a 3m span with beams at 400mm centres, a test load of 2.83kN would be equivalent to the in service load. Therefore the beam should not fail below 5.66 kN.²²
- Maximum deflection: is limited to span/300mm, therefore for a test load of 3.5kN the deflection for each beam should be less than 10mm.²³

Tables 6.12 and 6.13 show the results presented by Burroughs against the test criteria. Generally Beam A demonstrates a higher stiffness however both beams remain fairly constant throughout the test cycles, remaining below the fail criteria of 10mm at 3m spans and far exceeding the calculated target of 5.66kN.

The test process provided a number of useful learning points for the Project Team;

- The tests have confirmed that an OSB flange screwed to the top and bottom surface is a reasonable model for any infill panel design. This

21 Ibid., p. 11.
22 Ibid., p. 11.
23 Ibid., p. 11.



a) Web timbers are profiled as full length timbers, typically taken from rejected box section material, and cut to length.



b) Flange timbers with profiled groove to receive web timbers, cut to length and visually assessed for distortion and quantity and size of knots.



c) A setting out template is marked up with standard web and screw centres to assist assembly.



d) Place bottom and top flanges on bed of the assembly table and apply polyurethane glue to the grooves at locations set out on assembly table



e) Slot web timbers into groove of the bottom flange at marked locations



f) Slot the prepared top flange onto the tongues of the web timbers and clamp upper flange to back board



g) Pilot drill and drive 2 screws through top flange into each web timber at marked locations



h) Remove clamps and turn ladder over. Reclamp, pilot drill and drive 2 screws into each web timber.

Figure 6.48: Assembly process for Ladder Beam Type 01

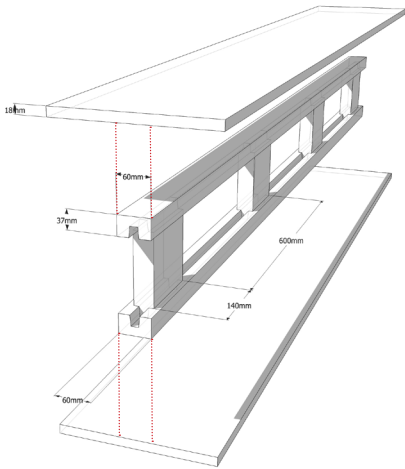


Figure 6.49: Resolved Geometry of Ladder Beam Type 01

	Ultimate limit state		Serviceability	Stiffness (kNm ² x10 ⁷)		
	Failure point - Significant non-linearity	Failure point - ultimate	Deflection at P = 3.5 First cycle	First Cycle	Second Cycle	Third Cycle
Criteria	P > 5.66 kN	P > 5.66 kN	d < 10mm			
1	5.6	7.4	6.025	15.87	16.16	15.87
2	5	12	6.16	14.99	14.99	12.34
3	9.5	10	5.47	16.75	18.51	13.52
4	10.5	15.5	5.3	18.81	16.46	17.93
5	8	11.5	5.7	17.05	18.81	17.63
Standard Dev	2.39	2.96	0.36	1.43	1.63	2.47
Mean	7.72	11.28	5.73	16.69	16.99	15.46
5th %	1.55	3.64	6.67	13.00	12.79	9.08

Table 6.12: Results from final testing performed by CERE at Glamorgan University: Beam A.
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), p. 13.

	Ultimate limit state		Serviceability limit state	Stiffness (kNm ² x10 ⁷)		
	Failure point - Significant non-linearity	Failure point - ultimate	Deflection at P = 3.5 First cycle	First Cycle	Second Cycle	Third Cycle
Criteria	P > 5.66 kN	P > 5.66 kN	d < 10mm			
1	7	9	8.54	11.17	12.05	11.46
2	6.5	8.9	9.6	10.29	11.17	10.87
3	5	9.5	8.59	10.58	11.46	11.46
4	8	12	7.15	13.52	14.11	13.81
5	8	9.5	8.33	11.46	12.34	12.34
Standard Dev	1.24	1.27	0.87	1.27	1.15	1.15
Mean	6.90	9.78	8.44	11.40	12.23	11.99
5th %	3.69	6.50	10.70	8.12	9.26	9.03

Table 6.13: Results from final testing performed by CERE at Glamorgan University: Beam B.
Source : Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009), p. 13.

allows testing to be carried out on individual ladder beams without the need to test a full panel within laboratory conditions;²⁴

- The incorporation of an additional OSB flange resulted in a change to the mode of failure, from a tension failure in the boom to a rotational failure at connection.²⁵ This is deemed to be of great use to the design of ladder beams as the performance of the ladder flanges are somewhat limited by the quality and standard availability of homegrown timber. In order to increase capacity, flanges would otherwise need to incorporate larger sections of timber or timber with a higher stiffness ie C24.
- There are a large number of alternative geometries and connections that can affect capacity, for example glued and / or screwed joints.

The resolved geometry incorporated into the Elements Europe Modular shown in Figure 6.50 is capable of spanning 3.0m for domestic loads when assembled at 400mm centres with an adequately connected sheathing of 18mm OSB, to the top and bottom flanges. If reduced to 9mm OSB, the maximum clear span is reduced to 2.3m.

MANUFACTURE

The resolved ladder beam consists of two types of components, shown in Figure 6.49. Two flanges are planed and profiled with a deep groove from 75x47mm

²⁴ Ibid., p. 15.

²⁵ Ibid., p. 14.

C16 Sitka spruce. Web timbers are planed and profiled with tongues to the top and bottom from 150x47mm Sitka Spruce, typically taken from offcuts and rejected timber from the manufacture of box sections. The process for assembly is shown in Figure 6.49.

6.03.2 SECONDARY STRUCTURE_ TY UNNOS LADDER TYPE 02

Following the completion of the CEREА testing on Ladder Beam Type 01, it was generally concluded that the design principles of the large section ladder beam had been resolved as efficiently as the geometry permitted and although options such as the addition of diagonal struts, side grain joints, deeper and tapered gluing channels, and diagonal screw joints could provide additional capacity it would not increase capacity dramatically.²⁶

Although Ladder Beam Type 01 is a resolved solution for secondary structural applications, it is limited in its application;

- The ladder beam is reliant on 18mm OSB to the top and bottom flanges to achieve spans of just 3m.
- The depth of ladder is limited due to the availability of timber dimensions capable of providing web timbers.
- It employs relatively large section 75x50mm timber, which is still prone to twist, as dimension critical flanges.

It was therefore proposed that a new approach should be taken to the design of ladder beams.

As detailed in Chapter 3.0, a number of small section Sitka spruce products are produced in high quantity for low value applications such as pallets and packaging. These typically use small section timbers taken from the outside of the tree, known as falling boards. The Project Team therefore proposed an alternative ladder beam made up of small section timbers, laminated together using techniques common to the pallet making industry, to form high performance engineered joists.

A number of alternative ladder geometries under went comparative tests by Coed Cymru before a resolved section was put forward for testing by TRADA. The proposed ladder beam design employs 2 continuous lengths of 20x60mm Sitka Spruce, in each boom, separated by short lengths of 20x100mm Sitka Spruce fixed perpendicular to the boom as web timbers. Web timbers are typically centred at a maximum of 600mm with the spacing between webs and booms infilled with short sections of 20x60mm Sitka spruce, see Figure 6.51. Using a hand held or machine nailing gun, a nailing pattern allocates 4 nails per web/boom connection, with nails fired through both sides of the timber booms. 3 nails

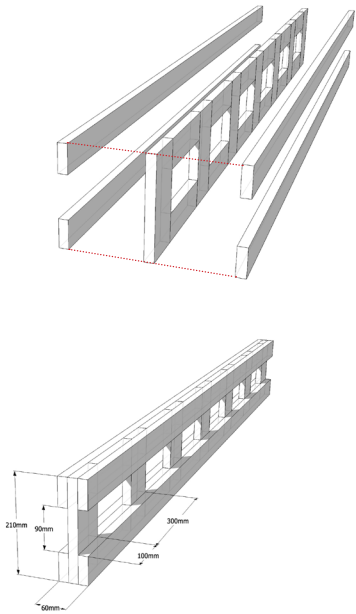


Figure 6.50: General arrangement of Ladder Beam Type 02

26 Ibid., p. 16.

are then fired into each boom infill timber.

TRADA TESTING

Structural testing on the Type 02 Ladder beam was performed by TRADA as part of the TSB SHSS House research project. Structural testing was performed on 30 ladder beams of two depths, 200 and 300mm, manufactured by Pontrilis Timber. Ladders were loaded to destruction using a four point test and the characteristic stiffness calculated.

A number of issues were encountered during testing that led to surprising results. The calculated stiffness from the TRADA testing was found to be considerably lower than expected, delivering results 15-20% lower than those calculated during preliminary Coed Cymru trials.²⁷

Burroughs identified a number of possible causes for this result suggesting that the quality of manufacture, specifically the inclusion of knots in excess of the timber specification, and the use of smaller nails than specified, could result in the drop in performance witnessed.²⁸

Table 6.15 Shows the resultant permissible spans and centres for domestic loading calculated by Burroughs based on the TRADA results. It also shows the comparative spans when ladders are employed with 18mm OSB applied to the top and bottom. The poor performance of the ladder beams under testing resulted in their exclusion from the TSB ETA certification, reverting instead to Ladder Beam Type 01.

Beam Depth	Beam Centres (mm)	Max Span without OSB (m)	Max Span With OSB (m)
200	400	2.1	2.73
	300	2.3	3.43
300	400	2.3	2.96
	300	2.5	3.43

Table 6.15: Results of testing on Type 02 Ladder beams performed by TRADA.
Source : Martin, T. (thomas.martin@burroughs.co.uk). (2010, October 11). – 2187 - Ty Unnos TSB - Ladder Beam Testing Results. Email to D.Jenkins (davidj@coedcymru.org.uk).

Following a number of additional trials and further assessment of the manufacturing process, Burroughs have recommended that testing be performed on a further sample of ladder beams incorporating a number of additional improved quality checks and manufacturing processes. It is believed that the resultant ladder beam will successfully span in the region of 3.0m at 300mm centres without the inclusion of OSB flanges.

27 Thomas Martin, (thomas.martin@burroughs.co.uk). (2010, October 11). – 2187 - Ty Unnos TSB - Ladder Beam Testing Results. Email to D.Jenkins (davidj@coedcymru.org.uk).

28 Ibid.



Figure 6.51: Preliminary trials with spruce based box panels using solid web joists with t+g internal and external linings.
Figure 6.52: Proposed geometry has male and female junctions to form a simple stacking junction.
Figure 6.53: OSB based alternative box panel.

6.04 THERMAL ENVELOPE

Post and beam construction is a considerable diversion from common practice in the UK’s house building industry. However as discussed in Section 3.10 there are a number of historical and modern precedents that successfully employ a post and beam frame for house construction. A well known example is the Huf Haus which combines a load bearing structure with high performance structural insulated panels. This combination of systems appears to be growing in popularity, and SIPs are now commonly employed with traditional oak frame construction. SIPs panels provide a number of benefits in this arrangement;

- They can be structurally useful, providing racking and load bearing capacity where necessary, and enables a habitable roof space.
- They provide very high levels of thermal performance, particularly air tightness, which has often been a challenging characteristic of post and beam frames.
- They can be adapted to most applications, with a good level of dimensional flexibility as manufacturing processes are well developed and heavily mechanised.

SIPs panels offer an appropriate solution for thermal infill in conjunction with the box section post and beam frame, and two of the initial building studies will employ SIPs panels manufactured by Cowley Timberwork. However it was felt that this solution did not fulfil the primary objectives of the research project. Although SIPs panels are now available from UK manufacturers, the majority of materials involved in the manufacture are not available from homegrown resources. The sustainability of SIPs panels can also be questioned due to the nature of the insulants employed in their manufacture. Insulations include expanded polystyrene (EPS), extruded polystyrene (XPS) or rigid polyurethane foam all of which are derived from petrochemicals and during production emit styrene and other hydrocarbons. This is however a discussion of relativity. SIPs panels provide a very high performance envelope for a small percentage of the energy required to produce a masonry construction.

It is considered within the scope of the resource and the industry to propose the development of a purpose made thermal infill panel, which employs a high percentage of homegrown timber and is based on natural insulations.

Drawing on the manufacturing precedent of local palette manufacturers, the Project Team proposed a small dimension cassette which combined Sitka Spruce ladder beams with a sheathing material providing internal and external finish. The provision of a secondary structural element such as the proposed ladder beams could enable the development of a panel similar in principle to SIPs systems but without the reliance on a structural insulation core.

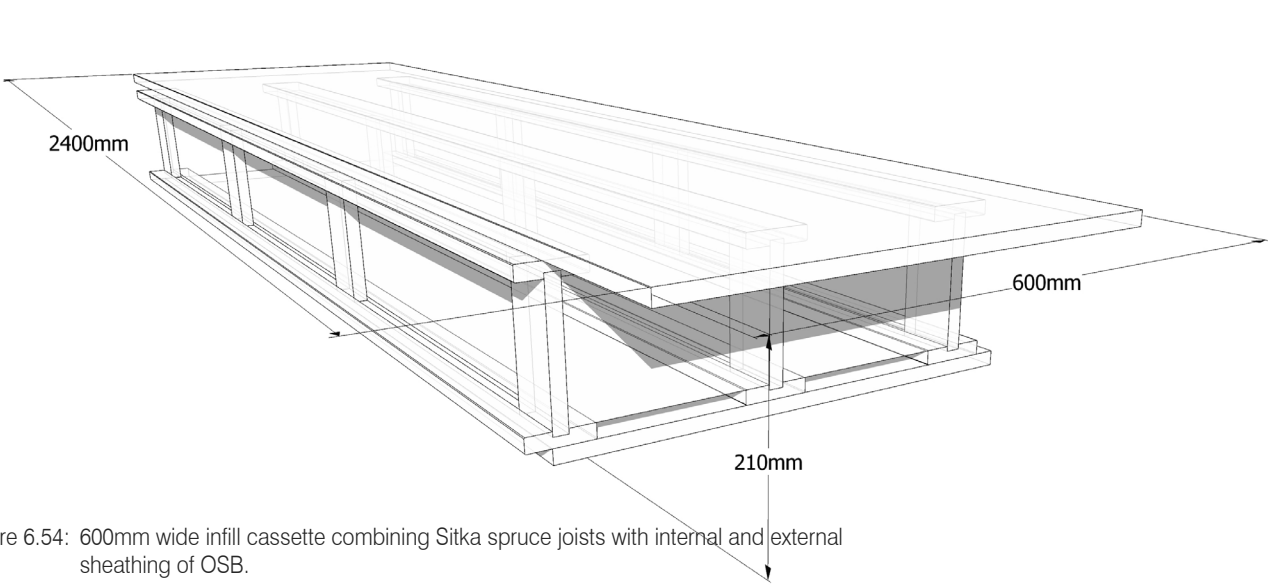


Figure 6.54: 600mm wide infill cassette combining Sitka spruce joists with internal and external sheathing of OSB.

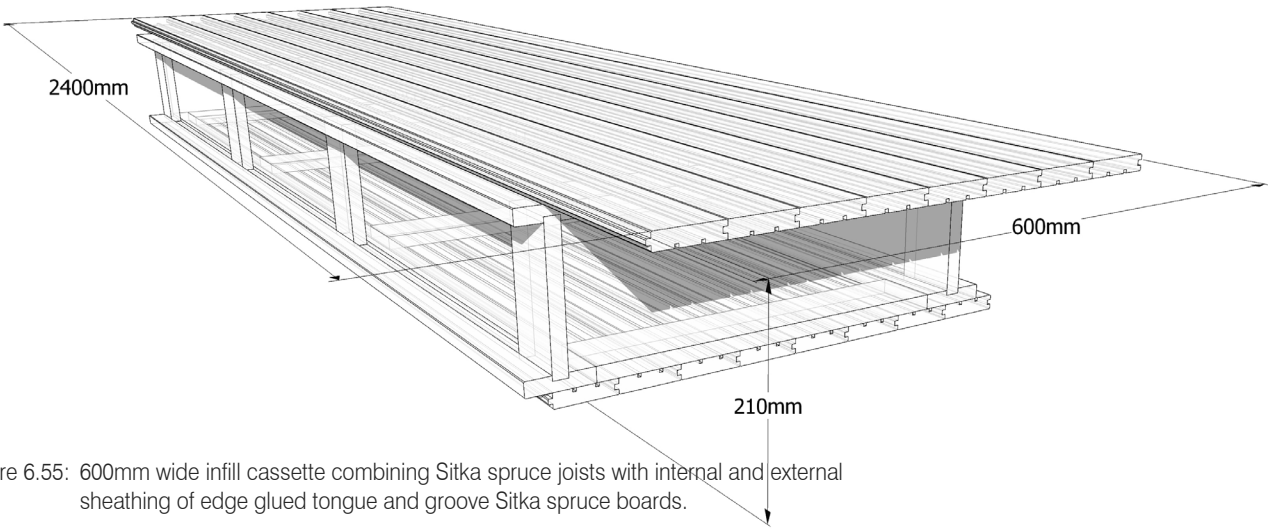


Figure 6.55: 600mm wide infill cassette combining Sitka spruce joists with internal and external sheathing of edge glued tongue and groove Sitka spruce boards.



Figure 6.56: Sitka spruce based panel prototype combining internal and external sheathing of T+G with spruce ladders.
Figure 6.57: OSB based panel prototype including air tightness seals.
Figure 6.58: Interior of spruce based panel showing substructure of additional noggins .

As discussed previously the feasibility study proposed the development of a box section element as a simple derivative of the primary load bearing structure. This could be similar in principal to the Lignatur product range as discussed in Section 3.10. Figures 6.52 - 6.54 show a selection of preliminary prototypes. These early prototypes suggested the potential for a ladder beam type component, making use of small section Sitka Spruce. The development of an independent spanning element encouraged an alternative approach to the design of infill panels. Rather than remaining tied to the geometry of the primary structural box sections, panels based on ladder beams could potentially be larger in scale and contain significantly less material.

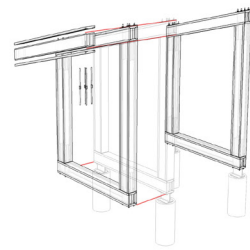
Two initial designs considered include a whole timber system that uses a small section spruce ladder beam with solid Sitka Spruce planking both internally and externally, and an OSB system which uses the same small section spruce ladders sandwiched between two layers of OSB, see Figures 6.55 and 6.56. Both systems combine low-tech processes, drawing on the local manufacturing processes of pallets, with potential for high insulative values using locally sourced natural insulations within a large structural void.

Whilst OSB based components are simpler to manufacture and engineer, they are less sustainable than a home grown timber based sheathing. There is a single UK manufacturer of OSB, based at a site in Stirling, Scotland however the majority of OSB used in the UK comes from international sources, typically Canada and North America. An OSB panel has the added disadvantage of limited panel sizes. Standard dimensions of OSB, in particular Scottish sourced Sterling board is supplied in sizes up 1220 x2440mm in thicknesses up to 25mm. It is possible to source 3m long OSB panels however these are generally sourced from Canada and North America. The use of a whole Sitka spruce infill panel therefore has the potential advantage of a greater flexibility in panel span, and if appropriate, could be used to provide internal finishes.

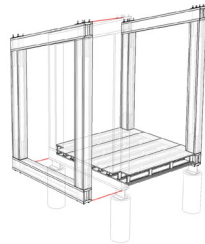
Table 6.16 shows a comparative study of natural insulations in relation to achieving a U-Value of 0.11 W/m2K, ie the value employed for BRE's Lighthouse Code 6 home, and the potential U-value of a 210mm depth, the depth of the manufactured box beam.

Insulation Type	Thickness to achieve 0.11 W/ m2k (mm)	Weight to achieve 0.11 W/m2k (kg)	U-value at 210mm thickness (W/m2k)
Hemp	350	20.16	0.19
Sheep's Wool_Thermafleece	320	11.52	0.18
Recycled Newspaper_Warmcel	290	14.6	0.16

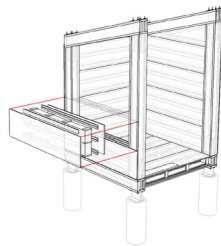
Table 6.16: Comparative study of alternative natural insulations for application in a panel system.



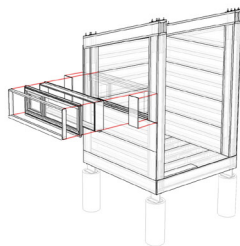
Portal Frame_ Laminated Box Sections of Sitka Spruce, jointed using threaded rod fixings or rigid steel or plywood corner sections, sit on lightweight foundations such as concrete piles or steel mini-piles



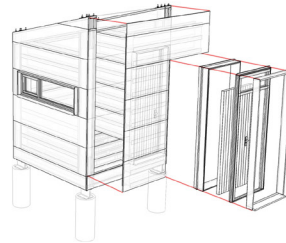
Floor Infil_ Suspended panel system spanning between portal frames combine Sitka Spruce ladder beams with panels of OSB or Spruce tongue + groove boarding. Infilled with natural insulations such as Warmcell, Sheep's Wool or Hemp



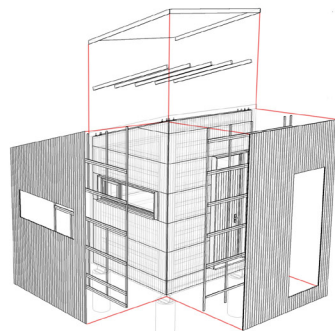
Wall Infil_ Panel system combining Sitka Spruce ladder beams with panels of OSB or Spruce tongue + groove boarding. Infilled with natural insulations such as Warmcell, Sheep's Wool or Hemp. Infil panels also form roof



Windows_ Dimensionally coordinated high performance window elements integrate with infill panels combining a spruce based window cassette with laminated heat treated softwood or hardwood windows



Doors_ Dimensionally coordinated high performance door elements also integrate with infill panels to complete the building envelope.



Cladding_ Any form of cladding, can finish the building envelope, including an independent masonry skin, although lightweight claddings such as timber or sheet metal will provide most efficient performance

Figure 6.59: Assembly sequence of prototype construction unit for the Royal Welsh showground consisting monopitched portal frames and spanning OSB based infill panels to floor, walls and roof.

OPPOSITE PAGE

Figure 6.60: Alternative infill panel arrangements

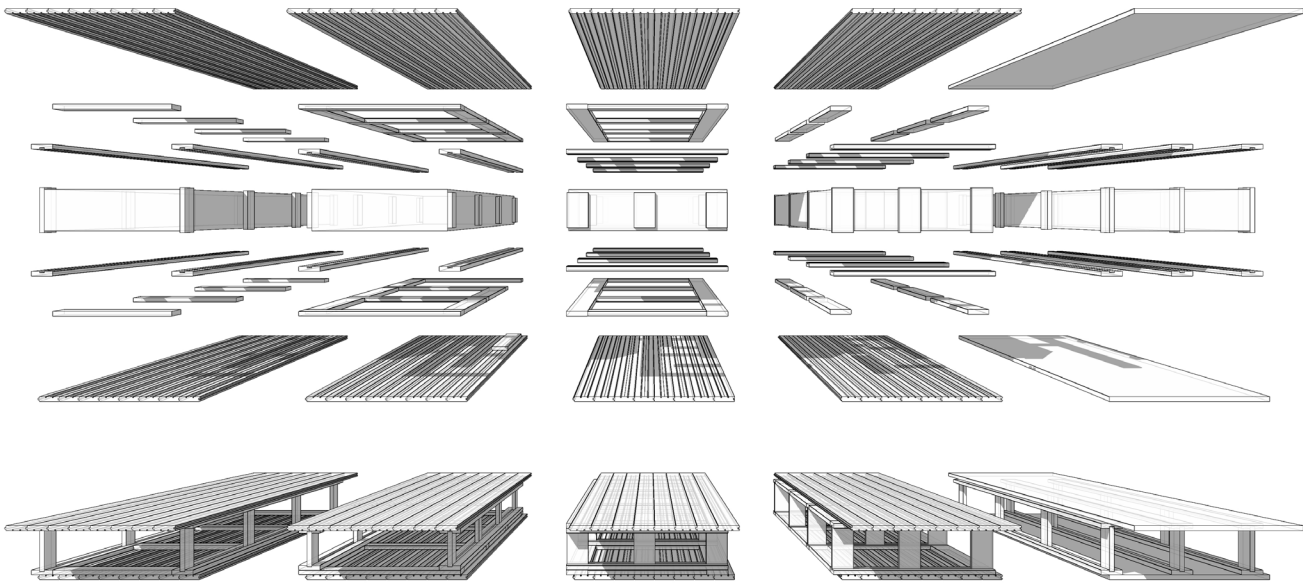
6.04.1 OSB + SPRUCE BASED INFILL PANELS

Following a number of trials with infill panels and ladders beams, a 2.4x2.4m mono pitched pavilion was conceived for assembly at the Royal Welsh Show 2008. Organised on a 600mm grid to the outer face of the primary structure, floor and roof panels were designed to span between portal frames with an extended OSB sheet to the upper face and a timber bearer on which the floor panels sits. Wall panels are designed as horizontally arranged panels spanning between columns with an extended OSB board overlapping the exterior of each column. Figure 6.60 describes the assembly sequence.

PROTOTYPE TESTING

As has been noted previously, ladder beams have been tested individually with the inclusion of an additional flange element to replicate the increased structural capacity of a panel. This has ensured that a system of panels does not require individual structural testing. The development of panel types therefore typically occurred through the detailed design and realisation of a number of prototypical studies. These will be discussed in more detail later in the study.

In order to test the comparative performance of the alternative sheathing types a simple test was designed and applied to 5 infill panel designs, some of which are shown in Figure 6.61.



Type 01 – longitudinal ladder with 20mm Sitka Spruce tongue and groove boarding with 20x100mm lateral board to assist fixing
Type 02 – longitudinal ladder with 20mm Sitka Spruce tongue and groove boarding with longitudinal and lateral subframe of 20x100mm boards
Type 03 – lateral ladder with 20mm Sitka Spruce tongue and groove boarding with longitudinal and lateral subframe of 20x100mm boards
Type 04 – lateral ladder with 20mm Sitka Spruce tongue and groove boarding with 20x100mm longitudinal rails
Type 05 – Longitudinal ladder with 18mm OSB



Figure 6.61: Panel 3 under load, applied in measured bags of wood pellets.
Figure 6.62: As above.
Figure 6.63: Panel 1 and Panel 4 consisting internal and external sheathings of T+G Spruce.
Figure 6.64: Proposed junction with ground floor box beam including a timber 'ledge' and extended internal sheathing.

In the test arrangement Panel 1, 4 and 5 are essentially arranged as 1,4 and 2 respectively. Panels 2 and 3 employ 18mm and 9mm OSB respectively with longitudinal ladder beams.

The test set up consisted of two box section lengths located to provide a 2m clear span. Panels were then loaded incrementally using 15kg weights. Deflections were recorded at 180, 260, 360, and 450 kg. The results of the deflections are shown in Chart 6.1.

Based on this test set up, a deflection of 6mm at 150kg would be the permitted design target. The study found that panels 1,2 and 5 successfully met this target. Of particular interest is the finding that short struts when combined with longitudinal flanges could perform similarly to 18mm OSB. This led to the recommendation that further investigations consider secondary structures spanning in both directions. This also led to the suggestion that a laminated sheathing products using homegrown timber could be a valuable future investigation.

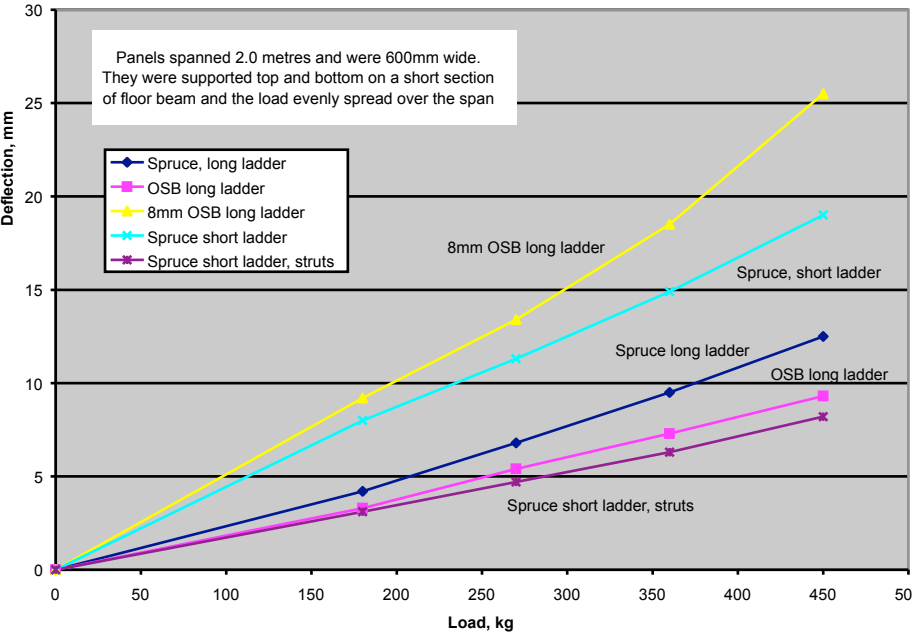


Chart 6.1: Deflection of prototype panels under load.
Source : Coed Cymru, *Panel Tests Mar 09* (Tregynon: Coed Cymru, 2009), p. 1.

In addition to this preliminary panel testing, Table 6.17 shows the results of a study performed by Burroughs to assess the maximum span of OSB between supports under a number of loading situations.

Loading	Maximum Span (mm)
Domestic	600 (δ)
Office	500 (δ)
Roof (No Wind Load)	600 (δ)
Wall (Wind Load Only)	900 (δ)

Table 6.17: The maximum span of 18mm OSB for alternative applications.
Source : Burroughs, *Technical Assessment of the Ty Unnos System*, p. 19.

6.05 SUMMARY OF FINDINGS

The development of home grown timber construction components has not followed a linear and concise route of prototyping, testing, development and certification. Due to the nature of available funding, the interests of commercial partners, academic research, and project deliverables such as prototypical studies have driven the development process. This has resulted in a fluid and evolving development cycle. The prototypical studies and realised component certifications therefore reflect the availability of tested and developed components at given points throughout the project timeline.

6.05.1 COMPONENT MATRIX

Table 6.19 shows the engineered home grown timber components available for construction applications and their relative performance characteristics. This summary of components is a guideline, and in most cases is supported by conclusive testing, enabling structural engineers to provide calculations to support construction. Table 6.18, produced by Burroughs provides a brief summary of the structural performance of homegrown timber components.

At time of writing, none of the individual construction components have received independent certification in line with the European standards. However, a number of components have been included in timber building kits that have successfully met the criteria required for ETA certification.

During development, a number of alternative engineered timber components have been proposed to make further use of homegrown timber. These include;

- Cross laminated solid timber panels
- Glue laminated large section solid and hollow section timber beams
- Load bearing ladder beams for wall construction

Of particular interest is the development of a cross laminated solid timber panel which may provide a homegrown timber based alternative to sheathing board products such as OSB, possibly to greater manufactured dimensions. There has however been limited development and testing of these proposed components due to restricted funding, therefore they will not be considered further within this study.

	Picture	Typical Achievable Span	Typical Centres
200x200mm Box Beam		3.5 m	3.0 m
200x300mm Box Beam		4.8 m	3.0 m
Tŷ Unnos Elements Ladder Beam		3.1 m	400 mm
New Ladder Beam (Current Results)		2.2 m	300 mm
New Ladder Beam (Anticipated Results)		3.0 m	300 mm
Solid 50x200 mm C16 Joist		4.0 m	400 mm
Diaphragm Panels	For lateral stability approximately 1 No 1.2m long panel is required per 1.5m length of perpendicular two storey wall (plus roof).		
Typical spans and centres for Tŷ Unnos Components			

Table 6.18: Typical Spans and Centres for the Principal Tŷ Unnos Components
Source : Burroughs, *Tŷ Unnos Component Toolkit*, 2nd edn (Cardiff: Burroughs, 2011), p. 5.

OPPOSITE PAGE

Table 6.19: Matrix of available homegrown timber construction components with associated performance and manufacturing characteristics.

PRIMARY STRUCTURE		SECONDARY STRUCTURE		CONNECTIONS		ENVELOPE		PROPERTIES
BOX BEAM	LADDER BEAM TYPE 01	LADDER BEAM TYPE 02	TIMBER JOINT	THREADED ROD	SPRUCE INFIL PANEL	OSB INFIL PANEL		
Standard Spruce C16 glued to form Structural hollow box beam and column to provide portal or box frame with moment connectors or diaphragm panels.	Small section Spruce combine to form ladder beams with solid timber booms and a web of solid timber posts at centres acting as vierendeel trusses.	Small section Spruce combine to form ladder beams with solid timber booms and a web of solid timber posts at centres acting as vierendeel trusses.	Moment Connector formed from plywood or solid timber laminates combined with steel laminates. Joint is formed from finger jointing laminates and screwing through beam and column.	Moment connector formed from threaded steel rods glued into end-grain timber of box column and bolted through bottom flange and steel shoe with steel transfer plates within joint.	Panel to provide floor, wall and roof infil spanning between box beam structure. Combines Spruce T+G board with Sitka Spruce Ladder beams. Infilled with natural insulation.	Panel to provide floor, wall and roof infil spanning between box beam structure. Combines OSB with Sitka Spruce Ladder beams, and infilled with natural insulation	DESCRIPTION	
Sitka Spruce C16 Homegrown Welsh Maximum dimensions length up to 5.4m width 75-225mm depth 36/47/63/73mm 3.1kN/m3 8000N/mm2 500N/mm2	Sitka Spruce C16 Homegrown Welsh Maximum dimensions length up to 4.8-5.2m width 75-250mm depth 18-25/36/47mm 3.1kN/m3 8000N/mm2 500N/mm2	Sitka Spruce Falling Boards Homegrown Welsh Maximum dimensions length up to 4.8-5.2m width 75-250mm depth 18-25/36/47mm 3.1kN/m3 8000N/mm2 500N/mm2	Sitka Spruce or Plywood C16 Homegrown Welsh or Import - - -	Threaded Steel Rod - Potential source in Wales - - -	Sitka Spruce T+G board C16 Homegrown Welsh Maximum dimensions length up to 4.8-5.2 m width 75-250 mm depth 18-47 mm 3.1kN/m3 8000 N/mm2 500 N/mm2	OSB with Spruce Ladder C16 Sterling Board- Scotland, Canada Maximum dimensions 2440 x 1220 standard 3660 x 1220 special order depth 6-28mm 5.5 kN/m3 1980 N/mm2 1080 N/mm2	MATERIAL CHARACTERISTICS	
4800 x 210 x 210/280 mm 19.8kg @ 2400mm 39.6kg @ 3000mm Warmcell/Hemp/Wool Warmcell~0.25W/m2-21.3/26.67kg Poor Routing/gluing/compression	4800 x 60 x 300mm 4.3kg @ 2400mm 5.4kg @ 3000mm - - - Routing/screwing/compression	4800 x 60 x 300mm 4.3kg @ 2400mm 5.4kg @ 3000mm - - - Routing/screwing/compression	600 x 600 x 134cs mm 4.3kg @ 2400mm 5.4kg @ 3000mm Uninsulated - - Gluing/screwing/compression	~900mm length Minimal Warmcell / Hemp / Wool - Potentially Poor End Grain Drilling/Gluing	4800 x 600mm 2400mm Spruce - 29.8kg 3000mm Spruce - 37.0kg Warmcell / Hemp / Wool Warmcell~0.16W/m2-38.5/47.8kg Poor Cutting/Assembly/Screwing	2440 x 1220mm 12mm OSB - 41.5kg 12mm OSB - 41.5kg Warmcell / Hemp / Wool Warmcell ~0.16W/m2 - 41.5kg 1.8 kg/(m.s.Pa)x10-9 at 50 Pa Cutting/Gluing/Screwing	COMPONENT PROPERTIES	
Physical loading_ Cowley • Hydraulic rams exerting load vertically • Failure reached at 7-9kN • Good failure with over 2kN applied between 'warning' and failure Analytical model_ Burroughs Deflection/ Fractures on Knots Max span 3.45m @ 2.9m centres using 210x210mm Max span of 4.8m @ 3.0m centres using 300x210mm	Physical loading_ Glamorgan • Recording prototypes against deflection and elastic response • Load testing to destruction • High levels of deflection and failure at 5-9kN Analytical model_ Burroughs Deflection/ Rotation of struts Max span 2.4m @ 600mm centres Max span 3.1m @ 400mm centres Dramatically increasing difficulty to achieve span over 3m	Physical loading_ Glamorgan • Recording prototypes against deflection and elastic response • Load testing to destruction • High levels of deflection and failure at 5-9kN Analytical model_ Burroughs Deflection/ Rotation of struts Max span 2.2m @ 300mm centres (current results) Dramatically increasing difficulty to achieve span over 3m	Physical loading_ Burroughs Moment resistance in junction with beam Max span 4.2m @ 2.4m centres	Physical loading_ Cowley • Deflection test using hydraulic ram • Push test to resist 1.0kN/m2 wind. • Deflection of 22.0mm Analytical model_ Burroughs Moment resistance of rods Limited to single storey applications	Physical loading_ Coed Cymru • Deflection test using Weights Analytical model_ Burroughs Deflection Span limited by ladder span Max ladder centres of 600mm Dramatically increasing difficulty to achieve span of 3m	Physical loading_ Coed Cymru • Deflection test using Weights Analytical model_ Burroughs Deflection Span limited by ladder span Max ladder centres of 600mm Dramatically increasing difficulty to achieve span of 3m	PERFORMANCE	
ETA 07 Timber Building Kit Certification as Ty Unnos Modular by Elements Europe awaiting individual certification	ETA 07 Timber Building Kit Certification as Ty Unnos Modular by Elements Europe	Not currently compliant	ETA 07 Timber Building Kit Certification as Ty Unnos Modular by Elements Europe	Not currently compliant	Not currently compliant	Not currently compliant	CERTIFICATION	

Chapter 7.0

Design Pattern Book

a design pattern book of affordable housing for rural Wales

7.01 INTRODUCTION

In Chapter 6.0, a number of engineered homegrown timber components have been developed and tested and proposed as structurally capable construction components. In this chapter, design studies will consider the application of these components in the design of a Pattern Book of House Types. Design studies will consider the performance, manufacture and assembly of the proposed components and combinations of components in conjunction with Space Standards to determine a set of coordinated Design Rules. These Design Rules will then be tested and applied in the design of a Pattern Book of House Types.

In Elizabethan England, the Pattern Book became an important medium of communication and dissemination of the Classical styles being practised in Italy and across mainland Europe. Lavish volumes of drawings and engravings catalogued many of the great architectural works of the era alongside elaborate ornamental details, such as porches and staircases, providing a wealth of precedent for the streets and squares of the Georgian cities and the middle class suburban villas and cottages alike.

However, the modern 'Design Pattern Book' largely originated in America to accompany the new technology of the Balloon Frame. Publications such as *“Cottage Residences”* and *“The Architecture of Country Houses”* by American Andrew Jackson Downing and *“Model Homes for the People”* by the Palliser Brothers are just examples of the many publications available showing detailed blueprints of a full range of house types. With the emergence of companies such as Sears Roebuck and Co, the Design Pattern Book became effectively a sales brochure, facilitating a mail order construction process, with hundreds of designs available for purchase as full construction kits ready for onsite assembly.

The Design Pattern Book remains an important application in the American house construction industry. Thousands of publications are available from bookstores and newsagents. Dedicated websites are also increasingly common, allowing clients to select and develop pattern book designs to suit their specific demands, closely tied into advertisements for construction products, services and contractors.

The pattern book concept is rarely employed in this form in the UK. It is common however for volume housebuilders and Housing Associations to develop a portfolio of standardised house plans which can be applied to development sites, with materials and 'character' detailing often tailored to the site context.

The concept of the Pattern Book is also frequently viewed with trepidation by the architectural community due to the generic and non site specific nature of its application. When considering the application of MMC, and specifically system builds, it is essential that construction methods are integrated into the



Figure 7.1: Single storey rural longhouse using the Ty Unnos construction system

Source: Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007), p. 24.

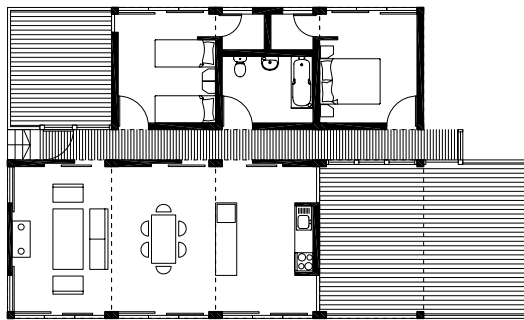


Figure 7.2: Rural longhouse laid out as a two bedroom four person starter home

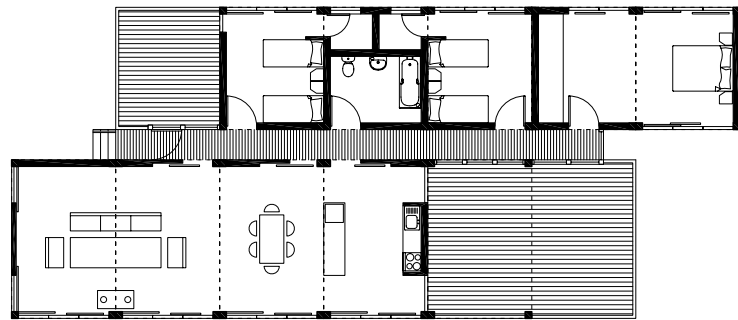


Figure 7.3: Rural longhouse laid out as a three bedroom six person family home using three additional structural bays

design process at a very early stage. Many MMC systems require a significant departure from typical design processes in order to encourage standardisation and fabrication efficiency. Subsequently the efficiency savings associated with construction systems can only typically be realised if the intended construction method is integrated into the design process at an early stage. This is often recognised as a significant risk in the use of MMC.¹

When considering the design of a system build it is feasible that the construction approach can be standardised at a number of physical scales to realise manufacturing and construction efficiencies. At the component scale, a range of dimensionally coordinated infill panels can be combined to form rooms of any shape and size within structural and dimensional rules. At the room scale, as promoted by Jørn Utzon with the Espansiva System, a range of standardised room modules can be combined to form homes of any shape and size. Or, finally at the building scale, where whole house volumes are standardised and prefabricated, such as those available through the development of the Elements Europe Modular System.

In the following chapter, the development of a Design Pattern Book will be interrogated through three stages of design. In order to develop a system appropriate for the broad social, geographical and architectural context of rural Wales, flexibility and adaptability of design have been identified as critical objectives of the research project. It is proposed therefore that standardising at the scale of components will offer the greatest potential for an appropriate level of design flexibility for this application.

The first study will consider the structure and dimensional organisation of engineered homegrown components. This organisation is applied and tested in both horizontal and vertical arrangements against the performance specification and component matrix. Of particular concern is the efficiency of dimensional arrangements in terms of manufacture and standardisation.

A second study will apply the proposed dimensional and structural rules to the design of rooms and combinations of rooms. In order to facilitate this structurally, each room is conceived as a pavilion with load bearing structure in each corner. Alternative room types, occupancy requirements and furniture organisations are tested against the performance specification, specifically Space Standards and Lifetime homes, but with close consideration for efficiency.

The final stage of the design development is to combine room types into whole house patterns. As rooms are conceptually conceived as structurally self sufficient pavilions, the development of house types will explore the theory of Additive Architecture as promoted by Jørn Utzon. As previously described,

¹ National Audit Office, *Using Modern Methods of Construction to Build Homes More Quickly and Efficiently* (London: National Audit Office, 2005), p. 21.

Utzon's Espansiva system combined room sized standardised units to form a limitless number of whole house design solutions. The autonomous nature of room volumes enabled the opportunity for further units to be added or removed as the future requirements for accommodation change. In marketing the Espansiva System, Utzon employed a number of resolved design examples to illustrate the potential design opportunities, but purposefully promoted the potential for clients and designers alike to tailor designs specifically to their wishes.

The final element of this study will apply the proposed Design Rules and Pattern Book to proposals for a rural development site. This study will consider the appropriateness of this design approach and illustrate, in conjunction with the Design Pattern Book, the potential opportunities and limitations of the proposed system of components when applied to the design of affordable rural housing.

7.02 DIMENSIONAL + STRUCTURAL ORGANISATION

Modern Methods of Manufacture in all industries rely on standardisation and repetition to improve efficiency. This is in the form of both components and processes. For example, the car industry incorporates thousands of individually unique components in each product, however the development of highly sophisticated, automated and disciplined assembly lines ensure that a single operative is working with a minimal number of specific components and repeating a limited number of tasks. The quantity and value of the manufactured products support this form of assembly operation and justify the high capital required to establish and maintain it.

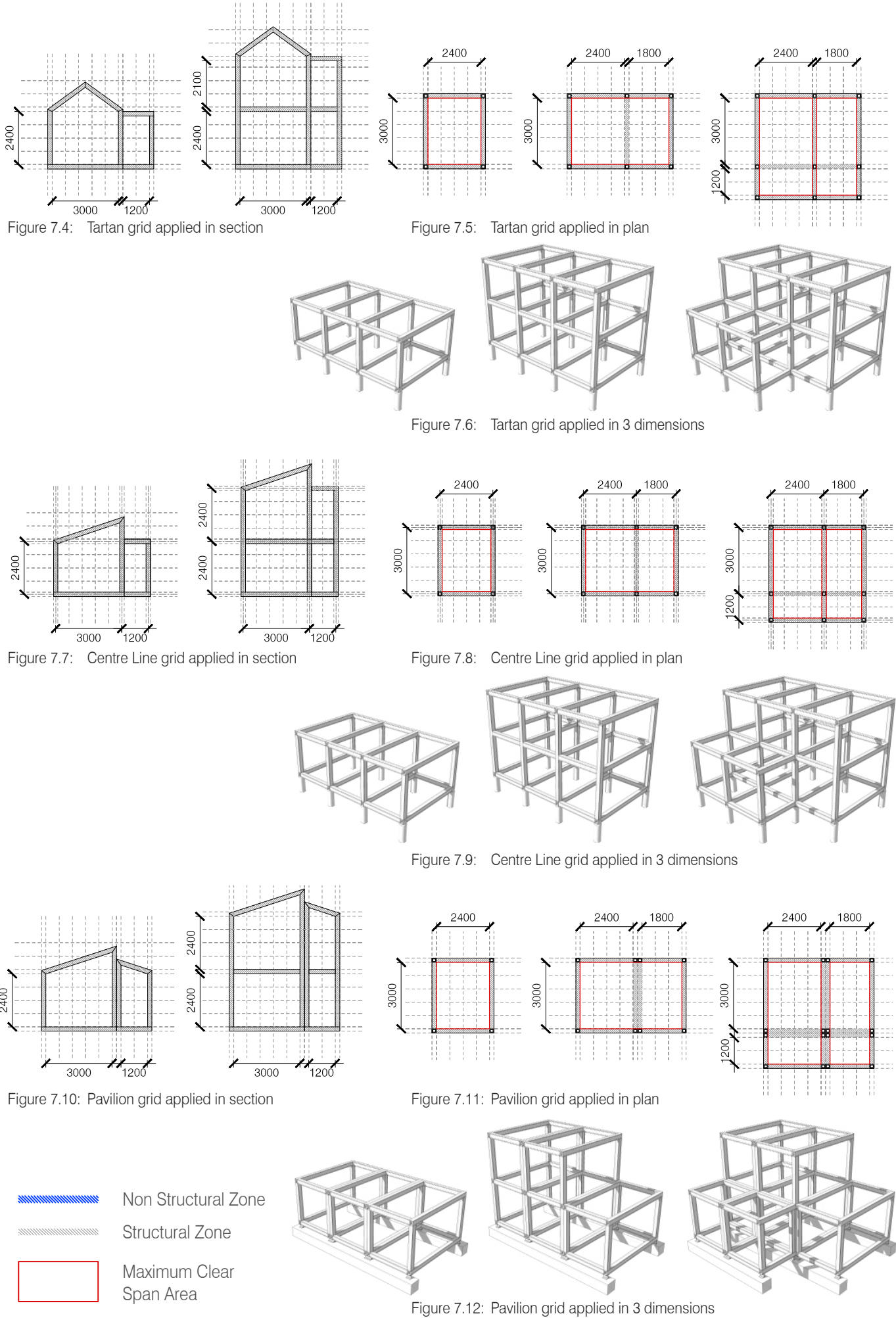
The limited capacity for investment available in the existing Welsh timber industry and the scale of market and product value will limit the nature of the processes and systems available for the manufacture of homegrown timber components. However a logic of standardisation and repetition is critical if the system is to be efficient to manufacture, design and construct.

At the scale of manufacture available to the project team, it became immediately apparent during prototyping that the key to making the system efficient was to strictly limit the number of components required for manufacture, and limit the raw material types required. This discipline needs to be enforced throughout the manufacturing process, including the sourcing of components such as nails and screws.

A common concern when considering the application of MMC systems and standardised components is the restrictions placed on design flexibility. Limiting the number of components available to a designer will inevitably reduce the options for design. However if a limited pallet of components are designed to be fully interchangeable, then the permutations or combinations of components can potentially facilitate a high level of flexibility in design.

It is therefore proposed that the key to standardisation and interchangeability is the design of an underlying dimensional organisation. The first stage of this study will therefore consider alternative options for the design of an organisational grid.

Four organisational grids have been considered, related to precedents and common construction practices, first applied to one autonomous room, then a combination of rooms in one direction and then in multiple directions.



Type	Figure	Key Features	Opportunities			Constraints		
			Design / Performance	Manufacture	Buildability	Design / Performance	Manufacture	Buildability
Tartan Grid (used by Walter Segal for the Segal Method)	7.4 - 7.6	<ul style="list-style-type: none">Primary structure is allocated a dedicated structural zone determined by the size of the required structure, shown as 200x200mmAll external and internal walls are set within the structural zone with width set out by the structural opening between primary structure, shown as multiples of 600mmWhen combined in multiple directions, load bearing is shared across single columns.	<ul style="list-style-type: none">Window and door opens will fall entirely within the infill zone therefore window and door openings can be dimensionally coordinated with infill panels and a good level of flexibility permitted in their positioning.Box section frame is likely to have lowest thermal performance within the thermal envelope therefore single columns placed at room scale intervals will minimise compromise.	<ul style="list-style-type: none">Dimensional coordination of infill panels is determined by the internal spacings between primary structure therefore all panels can be equal and standardised, and a high level of manufacturing repetition enabled.	<ul style="list-style-type: none">As panels are standardised, they will be interchangeable between positions, potentially enabling easier alterations both during and following the construction period.	<ul style="list-style-type: none">The width of the structural zone must incorporate all thermal and acoustic performance and structural requirements for internal and external walls to ease the detailing of junctions. Columns may need to be structurally oversized to meet high levels of thermal performance and internal walls may be substantially oversized to fill the predetermined structural zone.	<ul style="list-style-type: none">When considered in section, a single shared column must form junctions in multiple directions with floors and roofs potentially meeting at different points in the column height. This occurrence will result in complex joints which may be challenging to accommodate within the hollow box section frame.If all panels are accommodated within this dimensionally coordinated arrangement, designing standardised panels to overlap to provide diaphragm action becomes challenging and disruptive.	<ul style="list-style-type: none">The primary structure determines the width of the structural zone therefore a non-square section will generate different detailing scenarios for infill panels at corners.As internal and external walls are accommodated within the structural zone there is a likely chance of conflict between the primary structural columns and the distribution of services.
Centre Line Grid (commonly applied to timber frame panel systems)	7.7 - 7.9	<ul style="list-style-type: none">Primary structure, typically in the form of 150 x 50mm load bearing studs, are set out at equal centres, typically derivatives of standard board sizes, ie 1200mm.When sheathing boards are offered up to frames that are located at the centre lines of studs allowing for multiple panels to fall on a single stud.In the example, the grid is centred on the primary box section structure and laid out to a 600mm dimension.		<ul style="list-style-type: none">Primary structure can be set out to the dimensions of standard sheet materials, offering potential material savings.		<ul style="list-style-type: none">As box sections encroach into the corner panel grid lines, windows and doors that fall into these areas will be designed as a non modular width and will not be interchangeable with centrally located windows.	<ul style="list-style-type: none">The resultant overlaid grid has a reduced dimension each corner, due to the encroachment of the box section structure. Therefore a minimum of two panel types are required for each structural opening; a corner panel with a reduced dimension and overlap to abut the box section structure and standard width centre panel.	<ul style="list-style-type: none">Where overlaps are designed into standardised panels, the arrangement at junctions becomes critical to the standardisation of panels and the sequence of construction. For example internal overlaps centred on the grid line are not compatible at corners as one face will collide with its neighbouring perpendicular panel.
Pavilion Grid	7.10 - 7.12	<ul style="list-style-type: none">Each unit is designed as an autonomous structural module with load bearing structure in each corner.When considered as a single unit, the applied grid is the same as the tartan grid, however each additional unit maintains its structural autonomy with columns and structural zones doubled up.	<ul style="list-style-type: none">With each pavilion being structurally autonomous from its neighbour there is a greater flexibility over the arrangement of the structure in section, ie intermediary floors and roofs can be located at different heights without generating complex junctions.The principles of 'Additive Architecture' can be easily incorporated to allow autonomous structural units of space to be added or removed as the inhabitants needs change.			<ul style="list-style-type: none">Structural zones are doubled up between neighbouring pavilions resulting in excessive floor areas dedicated to internal partitions.Where multiple units are combined to create larger spaces, structural columns will be doubled or potentially quadrupled up.The box section frame is likely to be less thermally efficient than the surrounding thermal envelope therefore the doubling up of columns in external walls is likely to reduce the thermal efficiency of the envelope.	<ul style="list-style-type: none">The layout incorporates considerably more primary structural elements than the alternative layouts. This will result in each structural element performing less efficiently. Due to the quality and quantity of wood incorporated into their manufacture, it is likely that these elements will more expensive than a non structural infill panel therefore it is likely that this will increase the cost of the construction system.	

Table 7.1: Analysis of alternative grid organisations

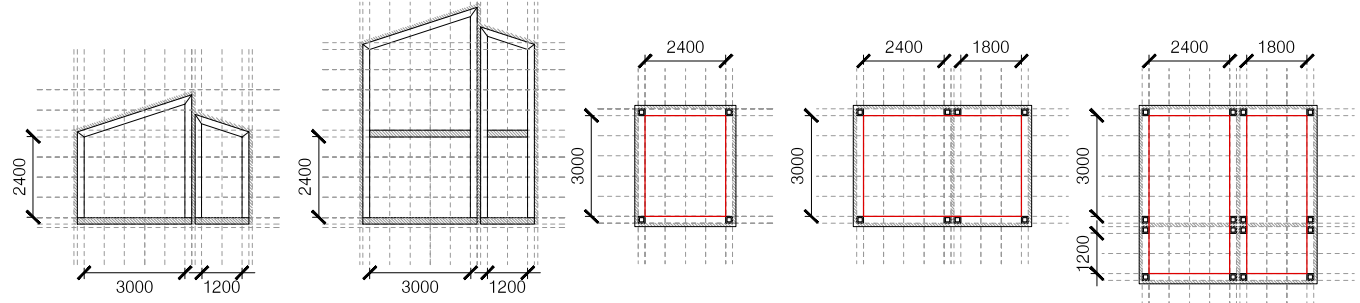


Figure 7.13: Utzon grid applied to single storey and multi storey sections.

Figure 7.14: Utzon grid applied to a single bay, multiple bays in one direction and multiple bays in two directions.

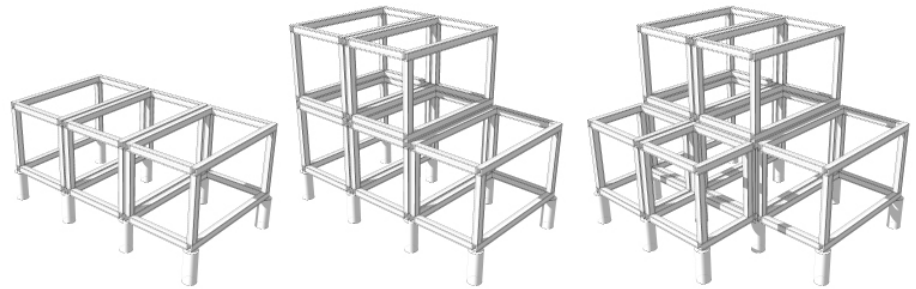


Figure 7.15: Utzon grid applied to a single bay, multiple bays in one direction and multiple bays in two directions.

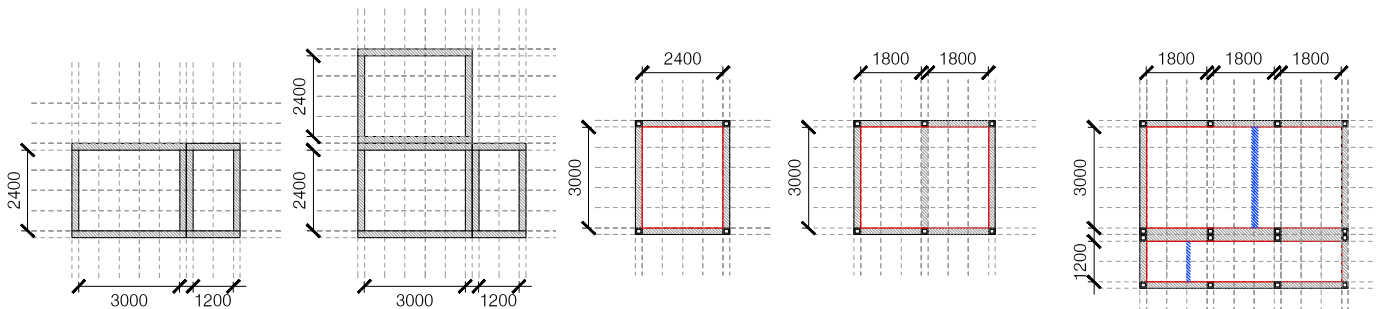


Figure 7.16: Volumetric grid applied to single storey and multi storey sections.

Figure 7.17: Volumetric grid applied to a single bay, multiple bays in one direction and multiple bays in two directions.

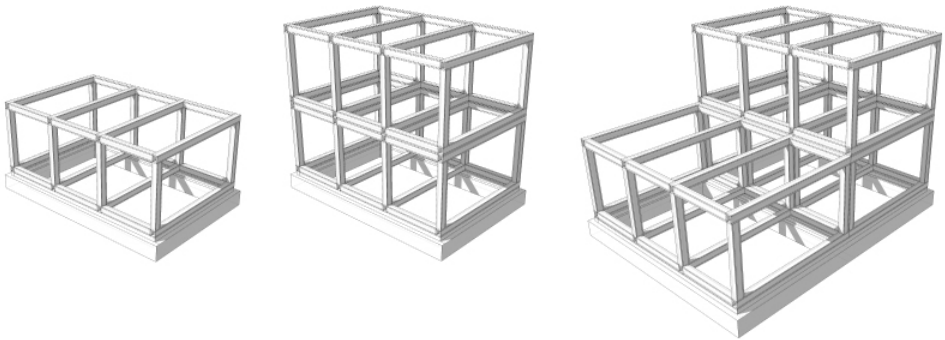
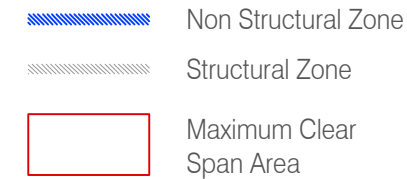


Figure 7.18: Volumetric grid applied to a single volume, multiple volumes in one direction and multiple volumes in two directions.



Type	Figure	Key Features	Opportunities			Constraints		
			Design / Performance	Manufacture	Buildability	Design / Performance	Manufacture	Buildability
Utzon Grid (Used by Jørn Utzon for the E s p a n s i v a System)	7.13 - 7.15	<ul style="list-style-type: none">As with the pavilion grid each unit is designed as an autononous structural module with load bearing structure in each corner.To the perimeter of each pavilion a fixed width 'module' line is included to allow for 'infill' panels to be fixed to the exterior of the primary structure to provide a thermal envelope, or, when falling between adjoining pavilions, as internal partitions.	<ul style="list-style-type: none">The width of the separating grid line can be determined by the specific performance requirements of the construction element. For example, internal partitions could be given a lesser width than that required for external thermal panels.The primary structure becomes a warm element, ie all insulations are installed on the cold side of the structure offering the potential to reduce thermal bridging caused by the primary frame.		<ul style="list-style-type: none">Utzon believed that this spacing enabled increased tolerances for the construction of the primary structure.As structurally autonomous pavilions, additional rooms can be added or removed without damaging the neighbouring construction elements. This is particularly facilitated with the Utzon grid over the pavilion grid by the disconnection of neighbouring	<ul style="list-style-type: none">It is highly likely that this arrangement will result in a large number of additional components required to ensure that the system can be flexible, ie an open plan space without a seperating wall between pavilions will leave a gap the width of the 'module' line between primary structural elements, in the floor, walls and roof which will require infill to complete the thermal envelope.	<ul style="list-style-type: none">As with the Paviiion layout, the Utzon grid requires considerably more primary structural elements and subsequently is likely to make the system more expensive.As the thermal panels are accommodated to the exterior of the frame, infil panels are not dimensionally coordinated to the organisational grid, and therefore it is likely that a number of types of panel will be required to make up each element.As the floor cannot be accommodated to the exterior of the primary structure, an alternative panel design is required for this element.	<ul style="list-style-type: none">As the primary structural elements are not structurally tied to one another there is an increased emphasis placed on the substructure to ensure the primary structure acts as one. It is likely therefore that point footings such as pad foundations are unsuitable as there is an increased possibility of differential movement.
Volumetric Organisation	7.16 - 7.18	<ul style="list-style-type: none">Employed by Elements Europe for Ty Unnos Modular.The Ty Unnos post and beam frame creates a 3 dimensional 'tube' limited in width by the maximum transportable dimensions.The portalised primary columns and beams are set out to the most efficient centres in regards to materials and structural elements.The tube is then broken up internally into individual rooms using non load bearing walls that are disassociated with the primary structure.	<ul style="list-style-type: none">The clear width of the structure is restricted by the maximum span of the box beam, however the length of each volume is only restricted by the maximum transportable size, and could be infinitely repeated, allowing for an unlimited length of space.	<ul style="list-style-type: none">The disassociation of internal walls from the primary structure, enables all primary and secondary structural elements to be determined by the most efficient arrangement in terms of materials, structural spanning capacities and cost.	<ul style="list-style-type: none">The system is almost entirely assembled offsite in factory conditions. On site, tasks are essentially associated with the preparation of footings and service connections, external claddings, particularly masonry claddings, and the delivery and craning of the finished units.As internal walls are not bound to the structural organisation, they can be located with complete freedom and could theoretically therefore be installed or adjusted on site prior to or following handover to suit the occupier's needs.	<ul style="list-style-type: none">As the position of the primary structure is not associated with the internal spatial arrangement, openings can not be placed with complete freedom as there is potential for primary structure to occur within the walls of rooms rather than at the meeting point of two perpendicular walls, and could therefore interfere with a desirable location for an opening.	<ul style="list-style-type: none">In order for volumes to be transported as finished modules, they require a reasonable amount of structural stability. Typically this results in the doubling up of structure in section, with a ceiling structure required to the lower module, in addition to a separate floor structure to the module above.When combined in plan, each volume will require its own arrangement of columns, generating large wall thicknesses.	<ul style="list-style-type: none">As each unit is delivered as a substantial volume, the assembly of modules on constrained sites may simply be unfeasible.

Table 7.1 Analysis of alternative grid organisations continued

7.02.1 DIMENSIONAL COORDINATION

The original feasibility study proposed a range of room modules based on a 600mm dimensional grid to generate five base modules;



Figure 7.19: Proposed spatial modules to coordinate with common domestic room types
Source : Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007), p. 19.

The development of smaller coordinated components however suggests that a greater range of modules may be feasible and appropriate to allow increased flexibility and adaptability for the design of housing. Rather than adopting a range of standard room types, a range of standard components could be adopted. The combination of these could provide the opportunity for a much broader range of options in plan, section and elevation, limited theoretically only by the permissible spans of structural elements.

The next stage of this design study is to consider alternative base dimensions for appropriateness and efficiency. This will be tested against;

- DQR and space standards for alternative domestic room types including Lifetime Homes compliance,
- Arrangement of openings, specifically the width and height of windows and doors,
- Speed of assembly and manufacture,
- Structural efficiency,
- Material efficiency including common construction component dimensions such as windows and doors,

Figures 7.20 - 7.27 show a number of potential room organisations using base dimensions of; 300x300mm, 400x400mm, 450x450mm, 600x600mm, 750x750mm, 900x900mm, 1000x1000mm and 1200x1200mm.

7.02.1.1 ROOM TYPES

The DQR provide a limited number of specific room sizes preferring to specify minimum single dimensions and minimum furniture requirements for compliant rooms. In comparison the LHDG provides dimensioned examples of compliant room arrangements for each house type, including furniture provisions, within its

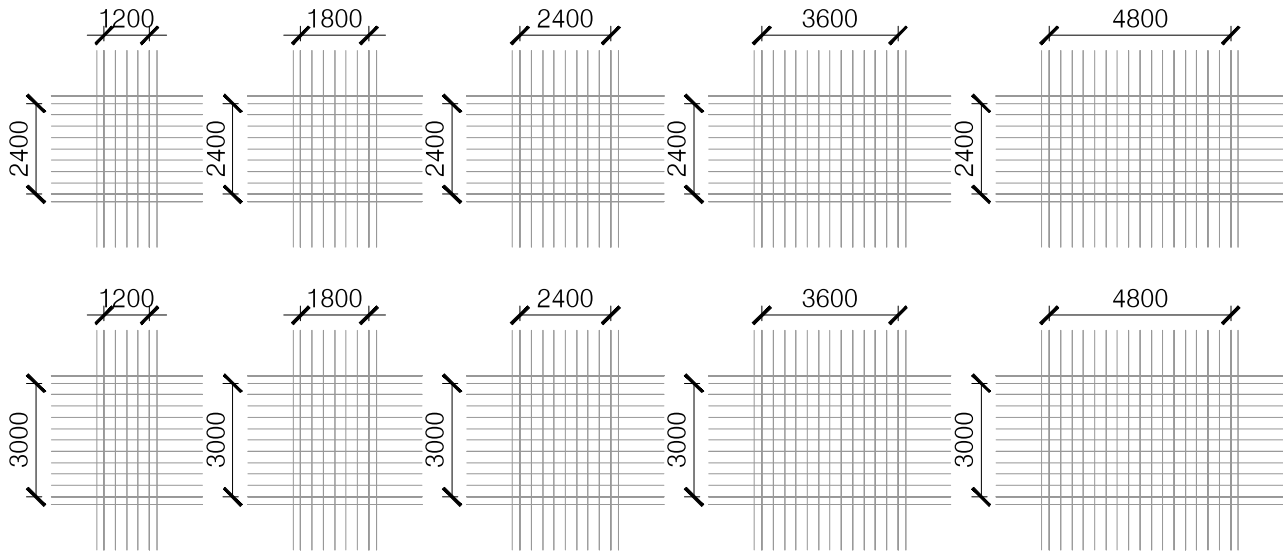


Figure 7.20: Tartan Grid using a 300mm base dimension

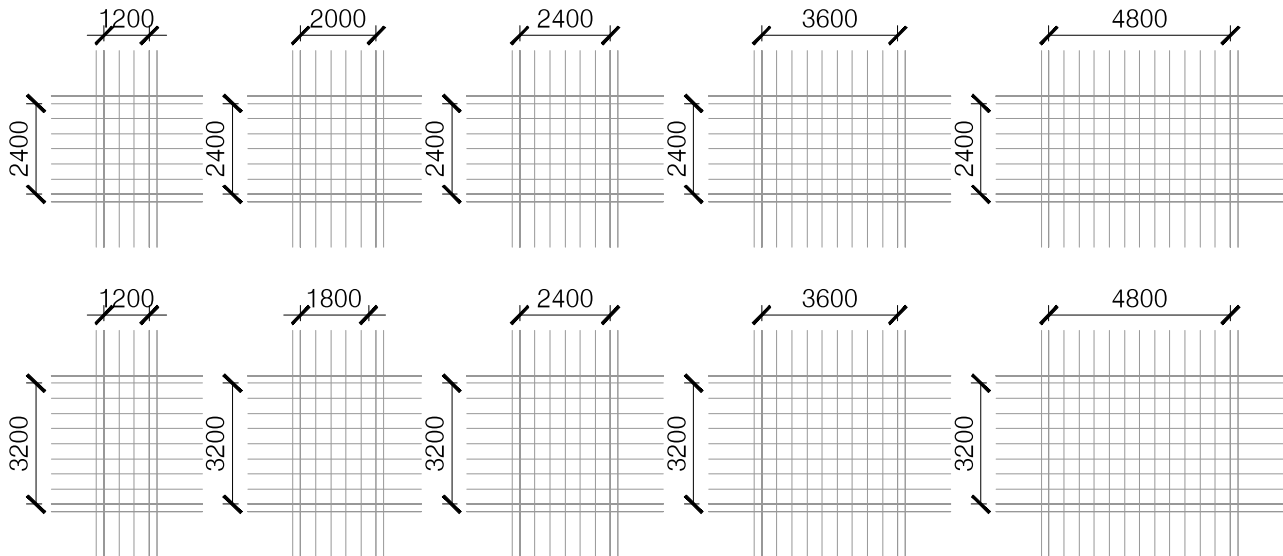


Figure 7.21: Tartan Grid using a 400mm base dimension

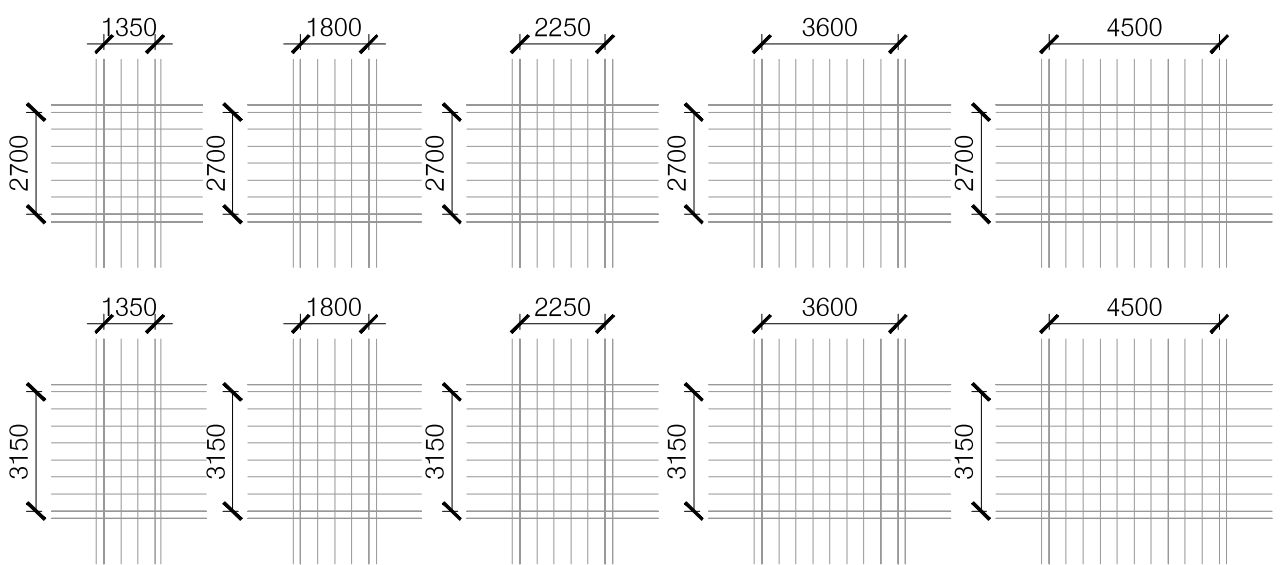


Figure 7.22: Tartan Grid using a 450mm base dimension

adjoining appendices.²

Table 7.2 shows a comparison of these minimum room sizes for affordable housing.

Two key factors must be considered for the assessment of proposed room types;

- The ability to achieve compliance with the minimum space standards set out in DQR.
- The ability to efficiently accommodate room types within standardised dimensional arrangements without providing excessive accommodation.

OBSERVATIONS

Generally it can be concluded that the larger the base dimension gets the less flexible and efficient the system becomes at achieving multiple room types. For example providing a bathroom using a 1200mm grid would result in a room of 2.4 x 2.4 m, approximately 30% larger than required by the LHDG and 45% larger than DQR. Larger base dimensions will therefore typically result in rooms being poorly sized and efficient for their function, and each room type will have an equal valency. In addition, larger base dimensions will result in less flexibility in the proportions of room arrangements, restricting design opportunities.

Table 7.2: Dimensions and areas of compliant room types taken from the Welsh Pattern Book Range and London Housing Design Guide.

Scheme	House Type	Bed No	Person	Lounge	Dining	Kitchen	Wc	Bath	Bed 1	Bed 2	Bed 3	Bed 4
Pattern Book Range April 2001	Flat Bungalow	1 Bed	2 Person	(l x b = area m ²)								
		1 Bed	2 Person	3.8 x 3.6 = 13.68		3.1 x 2.4 = 7.44		1.95 x 2 = 3.9	3.8 x 3.2 = 12.16			
	Flat Bungalow	2 Bed	3 Person		2.3 x				3.0 x 3.8 = 11.4			
		2 Bed	3 Person	3.1 x		x 3.15		x 2.15		3.1 x 2.3 = 7.13		
		2 Bed	3 Person	3.1 x		3.8 x 3.1 = 11.78		1.8 x	3.1 x			
	House	2 Bed	4 Person			3.1 x 3.8 = 11.78		2.1 x 1.8 = 3.78				
		2 Bed	4 Person									
	House	3 Bed	4 Person		3.2 x			2.1 x 1.9 = 3.99	2.8 x			
		3 Bed	4 Person	4.5 x		3.2 x	1.8 x 1.4 = 2.52	2.1 x 1.9 = 3.99		x 2.2		
	House	3 Bed	5 Person	x 3.1			x 1.9	1.8 x 2.1 = 3.78	3.3 x	2.1 x 3.85 = 8.085		
		3 Bed	5 Person			3.45 x	1.8 x 1.4 = 2.52	2.1 x 1.9 = 3.99	3.8 x 2.8 = 10.64	x 3.85	2.85 x 2.1 = 5.985	
London Design Guide	Flat	1 Bed	2 Person									
		2 Bed	3 Person									
	Flat	2 Bed	4 Person	3.5 x 3.7 = 13	2.6 x 4 = 10.4			2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8			
		2 Bed	4 Person	3.5 x 4 = 14	2.8 x 4 = 11.2			2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8		
	House	2 Bed	4 Person	3.7 x 4 = 14.8	3 x 4 = 12	2.1 x 1.15 = 2.4	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8			
		2 Bed	4 Person	3.7 x 4 = 14.8	3 x 4 = 12	1.9 x 1.4 = 2.7	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8			
	Flat	3 Bed	5 Person	4 x 4 = 16	3.2 x 4 = 12.8	2.1 x 1.15 = 2.4	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4		
		3 Bed	5 Person	4 x 4 = 16	3.2 x 4 = 12.8	1.85 x 1.945 = 3.6	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4		
	House	3 Bed	5 Person	4 x 4 = 16	3.2 x 4 = 12.8	1.85 x 1.945 = 3.6	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4		
		3 Bed	5 Person	4 x 4 = 16	3.2 x 4 = 12.8	1.85 x 1.945 = 3.6	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4		
	Flat	4 Bed	6 Person	4.25 x 4 = 17	4.0 x 3.6 = 14.4	2.1 x 1.15 = 2.4	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4	3.5 x 2.4 = 8.4	
		4 Bed	6 Person	4.25 x 4 = 17	4.0 x 3.6 = 14.4	1.85 x 1.945 = 3.6	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4	3.5 x 2.4 = 8.4	
Average	Average	Average	Average	4.0 x (3.5-4.25) = 15.56	4.0 x (2.6-3.6) = 12.72	1.85 x 1.945 = 3.6	2.1 x 2.1 = 4.4	4.0 x 3.2 = 12.8	4.0 x 3.2 = 12.8	3.5 x 2.4 = 8.4	3.5 x 2.4 = 8.4	

2 Mayor of London, *London Housing Design Guide: Draft for Consultation* (London: London Development Agency, 2009), pp. 78 - 81.

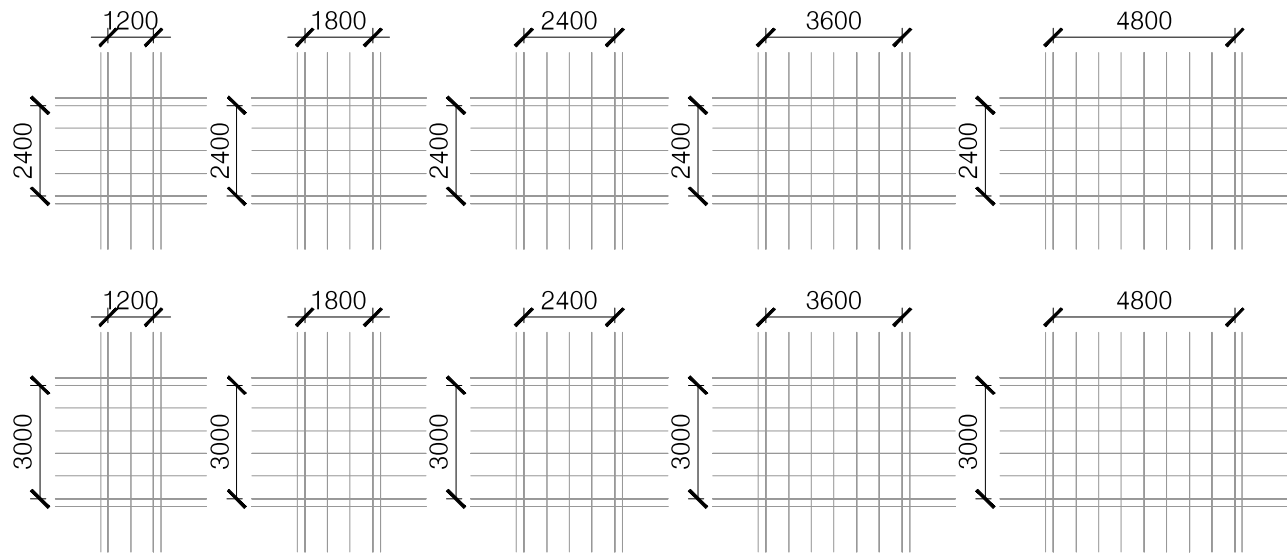


Figure 7.23: Tartan Grid using a 600mm base dimension

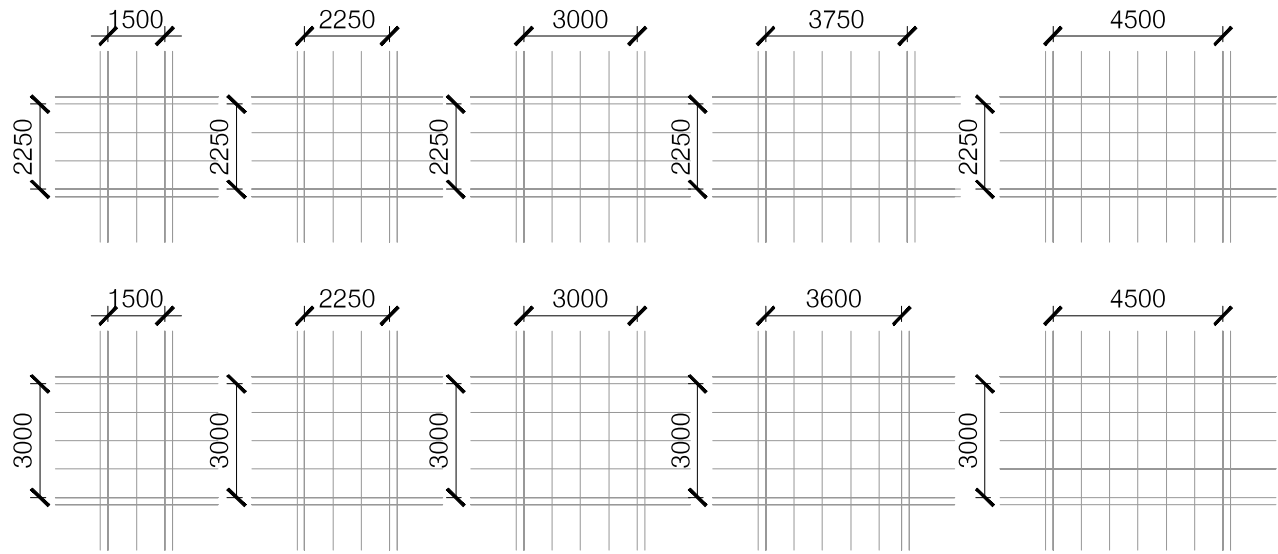


Figure 7.24: Tartan Grid using a 750mm base dimension

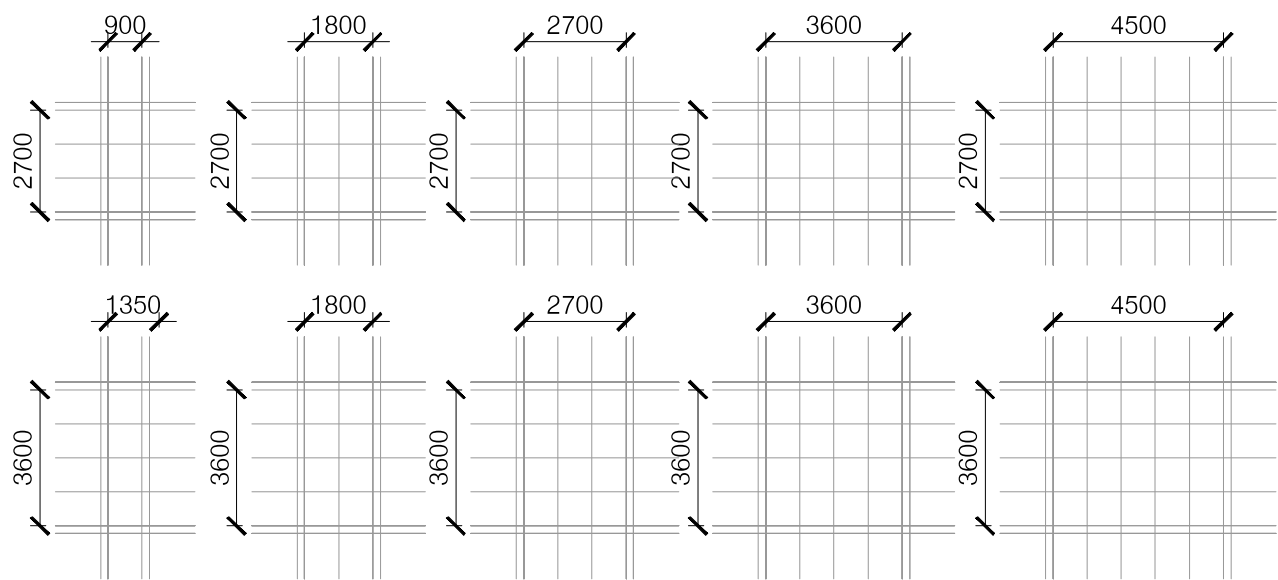


Figure 7.25: Tartan Grid using a 900mm base dimension

7.02.1.2 ARRANGEMENT OF OPENINGS

There are a number of national Building Regulations that influence the design of windows and doors;

Part B1- Fire Safety. For a window to be considered acceptable for emergency egress, the bottom of the openable area should not be more than 1100mm above the finished floor level.³

Part M1- Access To and Use of Buildings. For an external door to be considered acceptable for access by a disabled person it must have a minimum clear opening width of 775mm.⁴ Table 7.3 from Part M1 shows the minimum widths for internal doors and corridors to enable wheelchair users to turn into and out of doors.

In addition the Lifetimes Homes Standards require that living room window glazing should begin at a height of 800mm or lower.⁵

OBSERVATIONS

In plan, the larger the base dimension gets the less flexible the positioning of openings becomes, for example a 2 x 2m arranged on a 1m grid has only 3 potential arrangements of window width per wall whereas a 2.4x2.4m room arranged on a 0.6m grid has 10 potential arrangements of single openings.

A base dimension of 300, 450mm or 900mm is the most appropriate to enable a Part M compliant door opening of 775mm however this allows just 125mm for frame assembly. Compliant openings could be accommodated in 600 and 1200mm grids with the addition of a glazed side light.

When applied to vertical arrangement, a base dimension of 300 or 450mm would enable a sill height of 0.9m and head of 2.1m and 2.25m respectively. These resultant dimensions correlate closely with typical mass developer housing arrangements, and tie in neatly with the mostly frequently applied door head height of 2.1m. A 600mm grid gives less flexibility over the positioning of openings in section. A sill of 600 and 1200mm and head of 1800mm or 2400mm will require careful placement and design of openings, closely associated with specific localised functions.

7.02.1.3 SPEED OF ASSEMBLY AND MANUFACTURE

It can generally be assumed that the larger the component, the quicker

D o o r w a y clear opening width (mm)	Corridor/ passageway width (mm)
750 or wider	900 (when approach head- on)
750	1200 (when approach not head-on)
775	1050(when approach not head-on)
800	900(when approached not head-on)

Table 7.3: Minimum widths of corridors and passageways for a range of doorway widths.

Source : HM Government, *Building Regulations 2004: Part M Access to and use of buildings* (London: NBS, 2004) p. 67.

3 HM Government, *Building Regulations 2006: Part B1 Fire Safety : Dwellinghouses* (London: NBS, 2006), p. 19.

4 HM Government, *Building Regulations 2004: Part M Access to and use of buildings* (London: NBS, 2004), p. 66.

5 Lifetime Homes, *16 Design Criteria (up to 5 July 2010)* (London: Lifetime Homes, 2011), [http://www.lifetimehomes.org.uk/pages/design-criteria.html] <Accessed 14th May 2012>

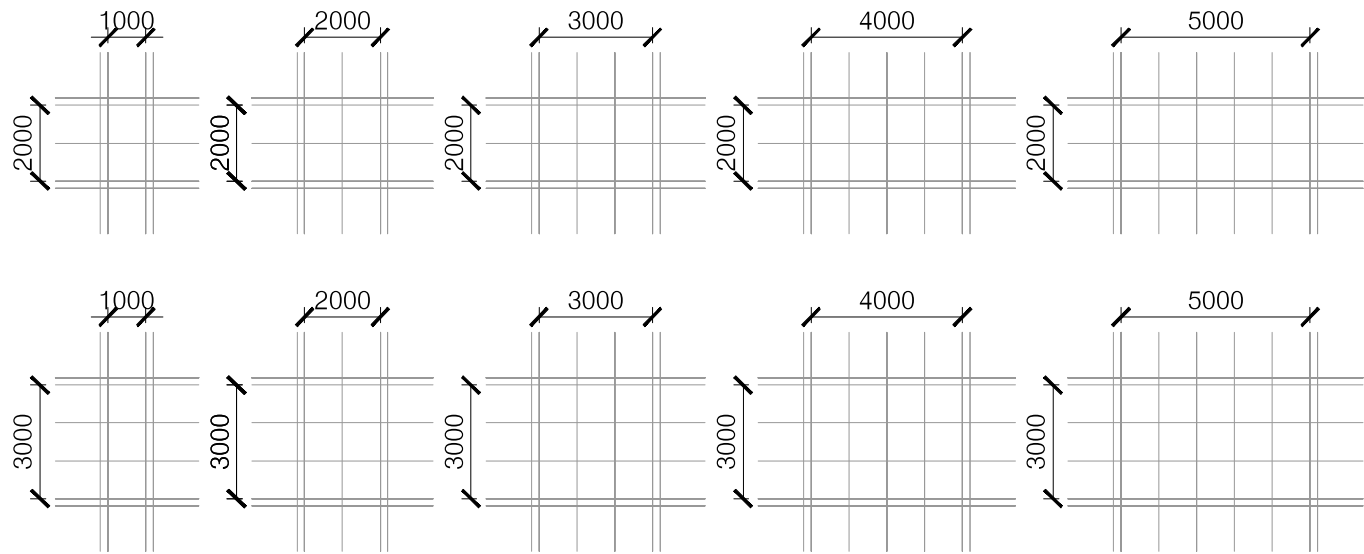


Figure 7.26: Tartan Grid using a 1000mm base dimension

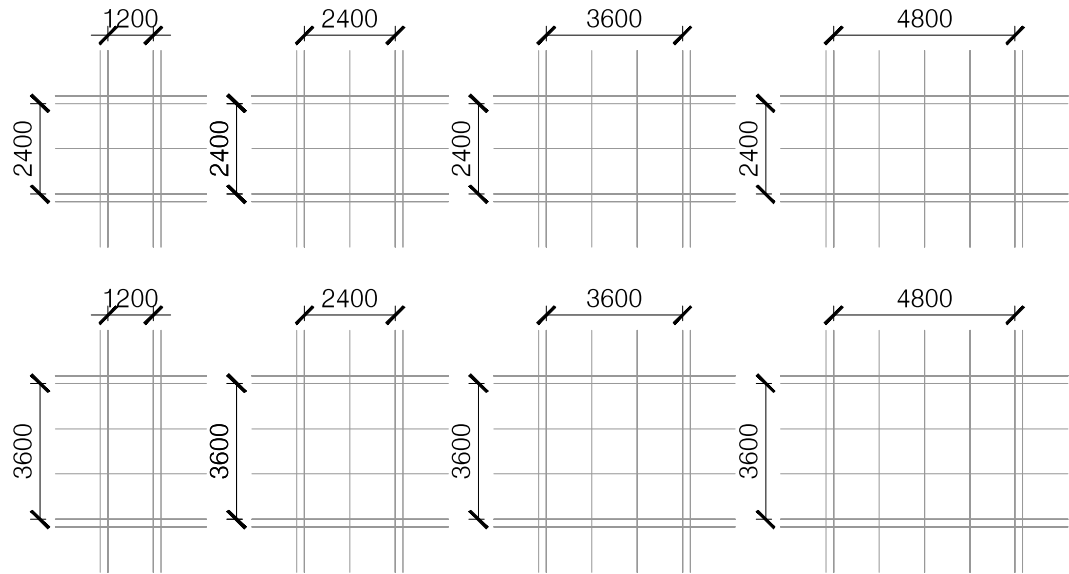


Figure 7.27: Tartan Grid using a 1200mm base dimension

assembly will be however this must be considered in conjunction with the weight assessment shown in Section 7.01.8. Where four people are required to complete a manual handling operation as opposed to two groups of two people completing two operations in parallel, the potential time saving associated with larger components may be insignificant.

The efficiency of component manufacture is closely to structural efficiency and material efficiency. A structurally efficient panel may result in a reduction in the number of components, for example a 1200mm panel requiring 3 ladder beams, compared with 2 no 600mm panels requiring 4 ladders. In addition a 1200x2400mm panel using a full board of OSB will require minimal processing, whilst a 300mm panel will require at least 3 additional cuts per OSB sheet.

7.02.1.4 STRUCTURAL EFFICIENCY

For a sheathing of 18mm OSB, Burroughs have concluded that a maximum span of 600mm is acceptable for domestic loading.⁶ In addition, ladder beam centres of between 300mm and 450mm have been analysed as the most efficient range for achieving useful spans in domestic applications.

Panel design is likely to require ladder beams positioned at the extremities of the panel width, neighbouring panels are therefore likely to have edge ladder beams immediately adjacent to one another. For panels less than 900mm it can therefore be assumed that the maximum centres of ladders will be approximately half the base dimension.

OBSERVATIONS

Dimensional grids based on 300,400 and 450mm are structurally inefficient as ladders are centred are between 150mm and 225mm.

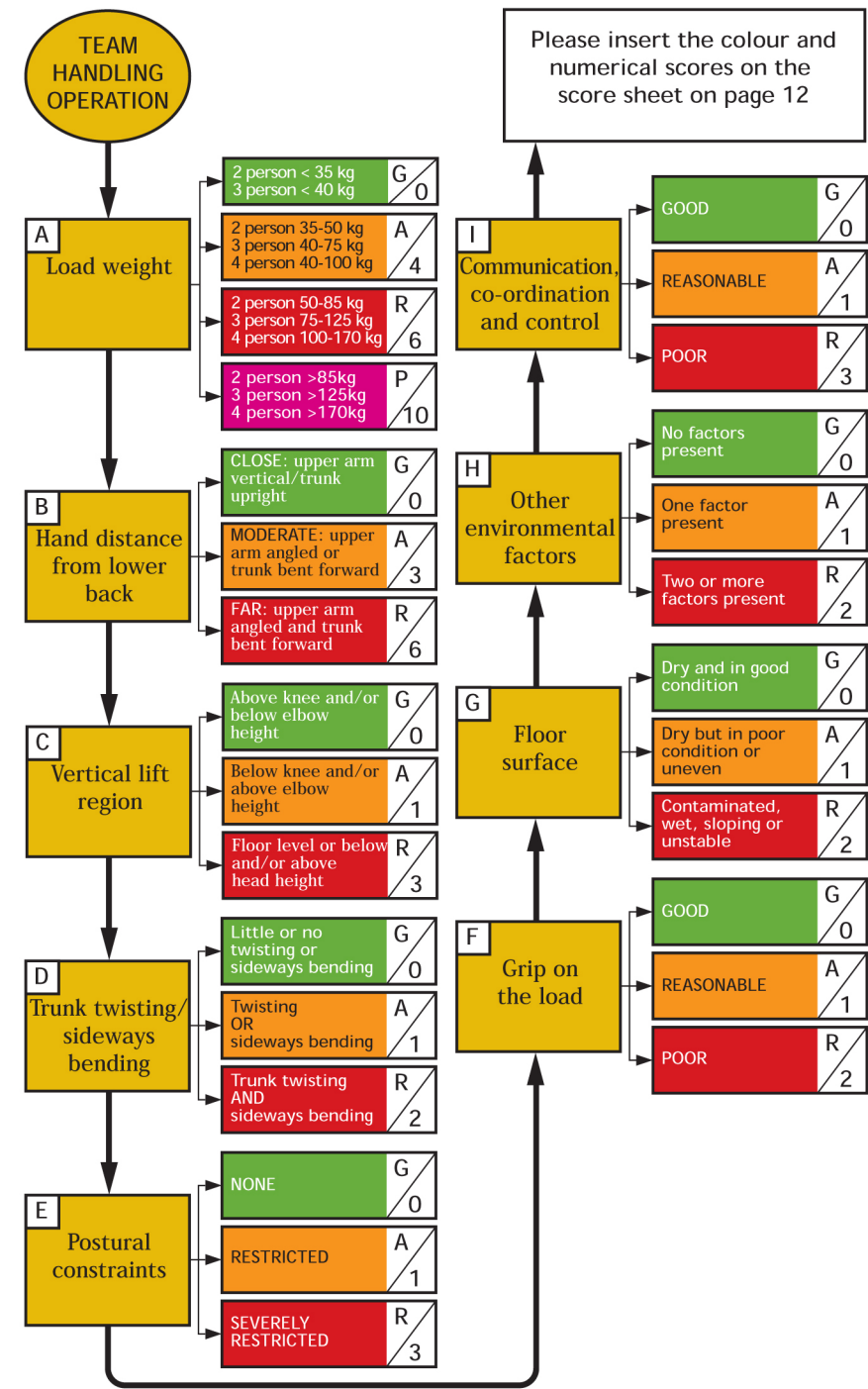
Panels with a width over 600mm will require an additional ladder beam at the centre line to reduce the span of the sheathing boards to below 600mm. Therefore 750, 900 and 1000mm panels are also structurally inefficient as ladders will be centred at between 210mm and 295mm.

Panels with a width of 600mm are relatively efficient structurally as ladders are centred at approximately 300mm and sheathing boards have a clear span of less than 600mm, however a 1200mm panel is likely to be the most efficient as four ladder beams are centred at approximately 360mm.

7.02.1.5 MATERIAL EFFICIENCY

The majority of common material sizes, particularly timber products are based on the imperial system of 3' and 6' critical dimensions. Thus all engineered boards, including OSB and plasterboard are still commonly manufactured to standard

6 Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009), p. 19.



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

Figure 7.28: Manual Handling Assessment Chart for assessing the risk associated with team handling operations.

Source: Health and Safety Executive, *Manual Handling Assessment Charts* (Suffolk: HSE Books, 2003), p. 11.

Figure 7.29: The HSE risk classification system.

Source: Health and Safety Executive, *Manual Handling Assessment Charts* (Suffolk: HSE Books, 2003), p. 2.

dimensions of 2440 x 1220mm, or 3' x 6'. Windows, although increasingly available made to order, are still commonly purchased 'off-the-shelf' based on imperial structural opening sizes therefore resulting in common window sizes of 600, 900, 1200, and 1800mm wide by 450mm, 600mm, 750mm, 900mm, 1050mm, 1200mm, 1350mm and 1500mm high. In addition, internal fixtures such as kitchen cupboards are typically arranged in derivatives of 150mm, with the most common width and depth of 600mm.

OBSERVATIONS

300, 400, 600, and 1200mm can all be delivered from a standard 1220x2440mm board product with minimal waste and with a reasonable allowance for cutting waste.

300,600 and 1200mm dimensions coordinate well with a large number of standard products as they tie closely to the widely employed metric dimensions 1', 2' and 3'.

7.02.2 COMPONENT WEIGHTS

The Health and Safety Executive does not prescribe a maximum weight limit in its Manual Handling Operations Regulations 1992. A purely weight based assessment of safe manual handling is considered to be too simplistic therefore an ergonomic approach is preferred which considers a number of additional characteristics of the task and assesses the risk associated.⁷ These characteristics include; the physical mechanisms associated with the task, the working environment, the physical characteristics of the load such as size and the availability of lifting points, and the capability of the proposed handler/s, including the ability for communication and coordination.⁸

Figure 7.28 shows the Manual Handling Assessment Chart as published by the Health and Safety executive to assist inspectors and employers to assess the risks associated with manual handling operations.⁹

In order to inform the design of components, in particular in terms of panel size and weight, I have looked to apply this assessment procedure to the range of component options. It has been necessary to make a number of assumptions based on the workplace and operations in order to focus on the risks directly associated with the design of components, these can be seen in Table 7.8.

It is assumed that these factors are identical regardless of panel size. It is worth noting that specifically E- Postural constraints may be affected by panel size, if

7 Health and Safety Executive, *Manual Handling: Frequently Asked Questions* (Bootle: Health and Safety Executive) <www.hse.gov.uk/contact/faqs/manualhandling.htm> [accessed 30 May 2012]
8 Ibid.
9 Health and Safety Executive, *Manual Handling Assessment Charts* (Suffolk: HSE Books, 2003), p. 1.

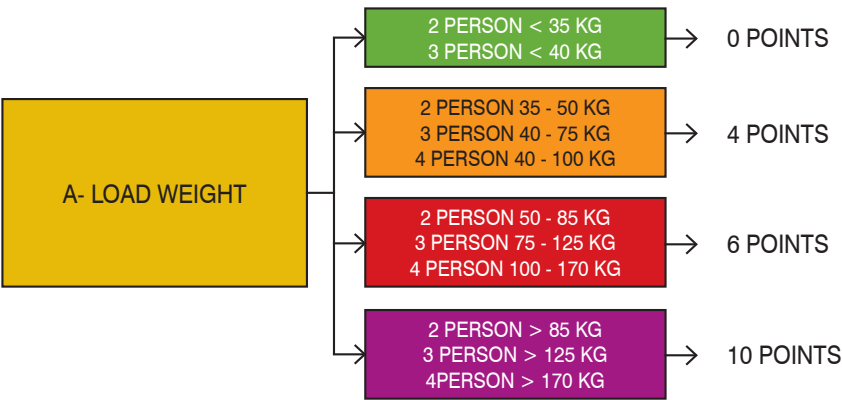


Figure 7.30: Weight assessment of standard floor panel with 2400mm clear span.
Source : Health and Safety Executive, *Manual Handling Assessment Charts* (Suffolk: HSE Books, 2003), p. 11.

Table 7.4: Weight assessment of standard floor panel with 2400mm clear span.

COMPONENT				PANEL WIDTH MM								
Description	Density	Length	Thickness	300	400	450	600	600	900	1000	1200	2400
	kg/m3	mm	mm	Weight kg								
18mm Grade 3 OSB External Sheathing	600	2400	18	7.78	10.37	11.66	15.55	15.55	23.33	25.92	31.10	62.21
190mm Spruce Ladder Beam @ max 450mm centres	weight=		7.88	15.76	15.76	15.76	15.76	15.76	23.64	23.64	23.64	31.51
190mm Warmcel Insulation	45	2400	190	6.16	8.21	9.23	12.31	12.31	18.47	20.52	24.62	49.25
18mm Grade 3 OSB External Sheathing	600	2400	18	7.78	10.37	11.66	15.55	15.55	23.33	25.92	31.10	62.21
WEIGHT OF PANEL				31.31	36.49	39.09	46.86	46.86	70.29	75.48	85.84	155.93
TOTAL INSULATED WEIGHT				37.47	44.70	48.32	59.17	59.17	88.76	96.00	110.47	205.18
NUMBER OF HANDLERS	assumed based on size			2	2	2	2	4	4	4	4	4

Table 7.5: Weight assessment of standard floor panel with 3000mm clear span.

COMPONENT				PANEL WIDTH MM								
Description	Density	Length	Thickness	300	400	450	600	600	900	1000	1200	2400
	kg/m3	mm	mm	Weight kg								
18mm Grade 3 OSB External Sheathing	600	3000	18	9.72	12.96	14.58	19.44	19.44	29.16	32.40	38.88	77.76
190mm Spruce Ladder Beam @ max 450mm centres	weight=		9.82	19.64	15.76	15.76	15.76	15.76	23.64	23.64	23.64	31.51
190mm Warmcel Insulation	45	3000	190	7.70	10.26	11.54	15.39	15.39	23.09	25.65	30.78	61.56
18mm Grade 3 OSB External Sheathing	600	3000	18	9.72	12.96	14.58	19.44	19.44	29.16	32.40	38.88	77.76
WEIGHT OF PANEL				39.08	41.68	44.92	54.64	54.64	81.96	88.44	101.40	187.03
TOTAL INSULATED WEIGHT				46.78	51.94	56.46	70.03	70.03	105.04	114.09	132.18	248.59
NUMBER OF HANDLERS	assumed based on size			2	2	2	2	4	4	4	4	4

Table 7.6: Weight assessment of standard floor panel with 3600mm clear span.

COMPONENT				PANEL WIDTH MM								
Description	Density	Length	Thickness	300	400	450	600	600	900	1000	1200	2400
	kg/m3	mm	mm	Weight kg								
18mm Grade 3 OSB External Sheathing	600	3600	18	11.66	15.55	17.50	23.33	23.33	34.99	38.88	46.66	93.31
190mm Spruce Ladder Beam @ max 450mm centres	weight=		11.77	23.53	23.53	23.53	23.53	23.53	35.30	35.30	35.30	47.06
190mm Warmcel Insulation	45	3600	190	9.23	12.31	13.85	18.47	18.47	27.70	30.78	36.94	73.87
18mm Grade 3 OSB External Sheathing	600	3600	18	11.66	15.55	17.50	23.33	23.33	34.99	38.88	46.66	93.31
WEIGHT OF PANEL				46.86	54.64	58.52	70.19	70.19	105.28	113.06	128.61	233.69
TOTAL INSULATED WEIGHT				56.09	66.95	72.37	88.66	88.66	132.98	143.84	165.55	307.56
NUMBER OF HANDLERS	assumed based on size			2	2	2	2	4	4	4	4	4

Table 7.7: Weight assessment of standard floor panel with 3600mm clear span.

COMPONENT			BEAM LENGTH MM						
Description	Density	Area	2400	3000	3600	4200	4800	5400	6000
	kg/m3	mm2	Weight kg						
210x210mm Hollow Box Section with 40mm Sides	390	27200	25.46	31.82	38.19	44.55	50.92	57.28	63.65
130x130mm Warmcel Insulation	45	16900	1.83	1.83	1.83	1.83	1.83	1.83	1.83
210x270mm Hollow Box Section with 40mm Sides	390	32000	29.95	37.44	44.93	52.42	59.90	67.39	74.88
130x190mm Warmcel Insulation	45	16900	1.83	1.83	1.83	1.83	1.83	1.83	1.83
TOTAL INSULATED WEIGHT 210 x 210mm	kg		27.28	33.65	40.01	46.38	52.74	59.11	65.47
TOTAL INSULATED WEIGHT 210 x 270mm	kg		31.78	39.27	46.75	54.24	61.73	69.22	76.71
NUMBER OF HANDLERS	assumed based on size		2	2	2	2	4	4	4

Risk Factor		Risk Banding	
B	Hand distance from lower back	Moderate	3
C	Vertical lift region	Below knee	1
D	Trunk twisting	Little twisting or sideways bending	0
E	Postural constraints	None	0
F	Grip on load	Reasonable	1
G	Floor surface	Dry but in poor condition	1
H	Other Environmental Factors		0
I	Communication, Co-ordination and Control		0
Total			6

Table 7.8: Generic risk factors assumed for all panel types.

for example, larger panels are applied to sites where there is a limited restraint on movement, or movement is hindered by scaffolding or existing constructions. However many of these factors are relatively generic to construction and can be controlled through good health and safety procedures and management during manufacturing, transportation and on site. Other factors, such as grip on load will be considered during the prototypical studies and may inform the design and specification of building components.

OBSERVATIONS

When infilled with insulation, in this case assumed to be Warmcel, only panels up to 300x3000mm can be considered acceptable for handling by two people. Panels without insulation have a broader acceptability, with 600mm panels falling just above the Amber risk level.

It has been assumed that handling by four people can be safely performed on panels 600mm wide and bigger with one person positioned on each corner. This assumption ensures that a 600mm insulated panel can be considered acceptable for manual handling by 4 people for panels up to 3.6m long.

Box beams are found to be manageable up to 4.2m in a 210x210mm section and 3.6m in 270x210mm when handled by two people.

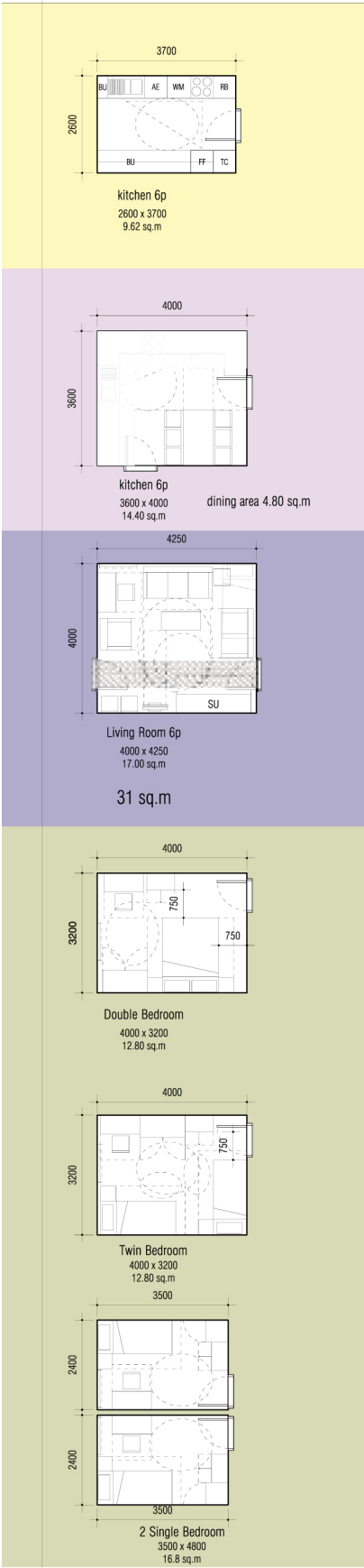
The results of this assessment are somewhat limiting, however advice from members of the construction industry suggest assessments such as these are often conservative and levels of red risk operations can be safely managed through considered health and safety plans.

7.02.3 SUMMARY

Based on these preliminary design studies I would propose that the most efficient dimensional solution for a component based system is to assume a 600mm dimensional grid in both horizontal and vertical organisation. This will ensure that available standard materials can be employed with minimal waste and it will enable a reasonable adaptability and flexibility to utilise standard 'off the shelf' window and door units. The 600mm grid poses a potential conflict with Part M compliant door openings however there are a number of design opportunities which will be considered in more detail later in the building studies.

I also propose that the post and beam primary structure will be employed to define the boundaries of all walls. Each room will therefore be considered as a pavilion with load bearing structure in each corner. This ensures that the positioning of openings in internal and external walls is entirely unrestricted by the primary structure. A 'tartan' type grid will be applied to the design of rooms, with spacings between primary structure in both the horizontal and vertical direction, set out strictly to a 600mm dimensional system. When combined into multiple rooms in all directions, the most efficient primary structure arrangement is likely to be in the form of a traditional post and beam frame with single columns falling at each node, ie at internal and external wall junctions, however this potentially places greater demand on the design of frame junctions. This will be further tested through the design and construction of prototypical studies.

4-bed, 6-persons



7.03 DESIGN ROOM TYPES

As previously discussed in Section 5.03, the Welsh Assembly Government's Design Quality Requirements (DQR), the Lifetime Homes Standard and the London Housing Design Guide (LHDG) provide guidance and a minimum requirement for floor areas, room sizes and furniture requirements, when designing affordable housing. Although originally proposed as a series of fixed size modules, it is evident that in order for rooms to be space efficient, they must be flexible and adaptable to the requirements of the proposed inhabitants and dwelling type. In Appendix 1 of the LHDG a comprehensive matrix of room arrangements combines Space Standards and the Lifetime Homes Standards, to produce a recommended organisation for each room type against the number of people to be accommodated.¹⁰ An example of this is shown in Figure 7.31

In this stage of the design study, the proposed dimensional arrangement and structural limits have been applied to the design of room types. The proposals for each room type can be seen in Figures 7.32 - 7.38. These drawings replicate the recommended arrangements proposed by the LHDG and the Welsh DQR, in order to test;

- The efficiency of the 600mm dimensional organisation,
- The level of flexibility permitted in the design of rooms when organisational rules are applied to ensure manufacturing and structural efficiency,
- The permissible limits of the proposed components against the requirements of room designs.
- Compliancy with Space Standards.

OBSERVATIONS

Generally the 600mm grid can be employed to provide a broad range of room geometries. Generally however the room types proposed by the LHDG are not directly replicable using the 600mm grid. This results in the proposed room types being, sometimes significantly, smaller or larger than the recommended sizes. Of particular note is the bathroom, proposed by LHDG as 2.1m x 2.1m is most closely replicated on a 600mm grid at 2.4 x 2.4m, a 30% increase in area.

Horizontal circulation is another area requiring consideration. Circulation widths are typically determined in Building Regulations and the Welsh DQR by the required approach to doorways. The LHDG however sets a simplified standard of a minimum corridor width of 1050mm with internal door widths of 775mm.¹¹ To maintain the 600mm organisation a 1200mm width must be applied. This increases circulation by approximately 15% per m². However considering

Figure 7.31: Compliant room types applied to a 4 bed 6 person dwelling.
Source : Mayor of London, *London Housing Design Guide: Draft for Consultation 2009* (London: London Development Agency, 2009), p. 79.

10 Mayor of London, *London Housing Design Guide: Draft for Consultation 2009*, pp. 78-81.
11 Ibid., p. 41.

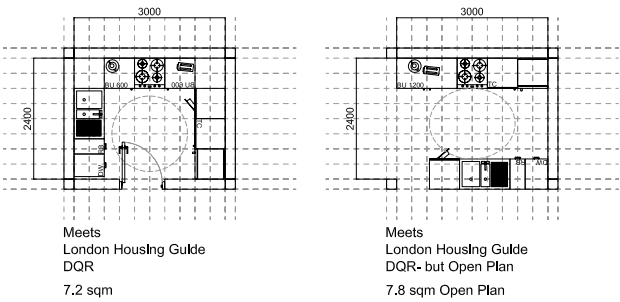
corridors as independent structural pavilions is unlikely to be structurally or spatially efficient in most cases. It is possible therefore that circulation will be used to infill areas of the plan where small rooms such as bathrooms and single beds combine with larger rooms. Figures 7.34 and 7.35 show a number of options to demonstrate this arrangement. As the efficiency of associating internal walls with the dimensional grid is less critical in these arrangements, there is greater flexibility to diverge from the grid to achieve a more efficient use of space. Areas of left over space could be also utilised to provide dedicated storage facilities.

Currently, as detailed in Section 6.04.1, the Ty Unnos ladder beams can span up to 3.1m at a maximum of 400mm centres. In order to ensure that rooms do not become disproportionately long and thin, the Welsh DQR places an average width requirement of 3.1m for living rooms, and in the case of living rooms that provide access to an adjoining room, this is increased to 3.3m.¹² Currently the tested ladder beam components are not capable of meeting both of these requirements. Figure 7.33 demonstrates the effect on living room proportion if a room width is fixed at 3m and the length is adjusted to meet the increasing occupancy and furniture requirements for different dwelling types.

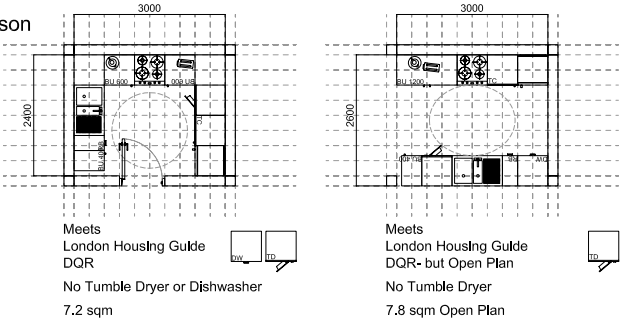
If the design of rooms is restricted to a primary structure with a maximum clear span of 3m, then an alternative solution would be to accommodate larger rooms such as living spaces within multiple bays of structure. Whilst this can be easily accommodated and will successfully meet the required space standards, it results in a less efficient structural arrangement, with multiple spans of less than 2.4m being common. Figure 7.33 illustrates this scenario applied to a double bedroom, with multiple bays of 1.8m employed to achieve the required width of 3.2m, just beyond the permissible ladder beam span. For the design of living spaces, complementary functions such as living and dining or dining and kitchen could be combined to create larger open plan spaces accommodated within multiple bays, making more efficient use of structural capacity. The introduction of multiple bays to achieve single rooms however can also result in a reduced design flexibility. In this arrangement, external walls to the room will be broken by structural columns thus potentially limiting the type and size of openings that can be accommodated.

12 Welsh Assembly Government, *Welsh Design Quality Requirements : Design Standards And Guidance* (Cardiff: Welsh Assembly Government, 2005), p. 11.

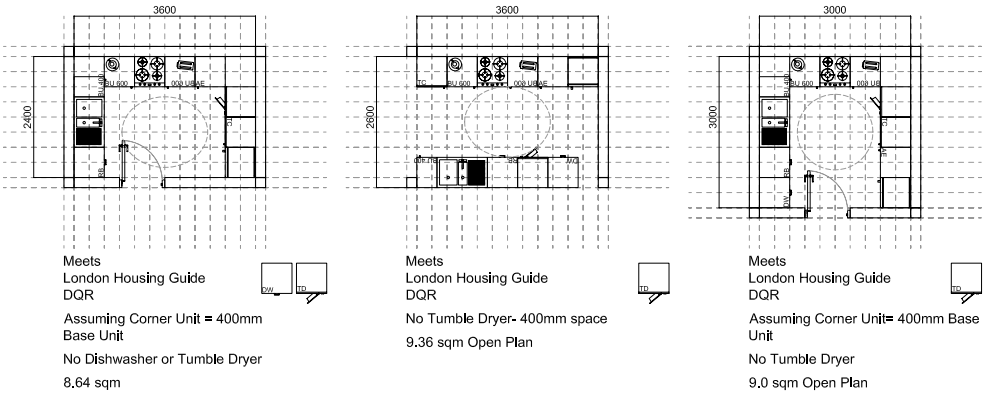
2 PERSON



3 + 4 PERSON



5 PERSON



6 PERSON

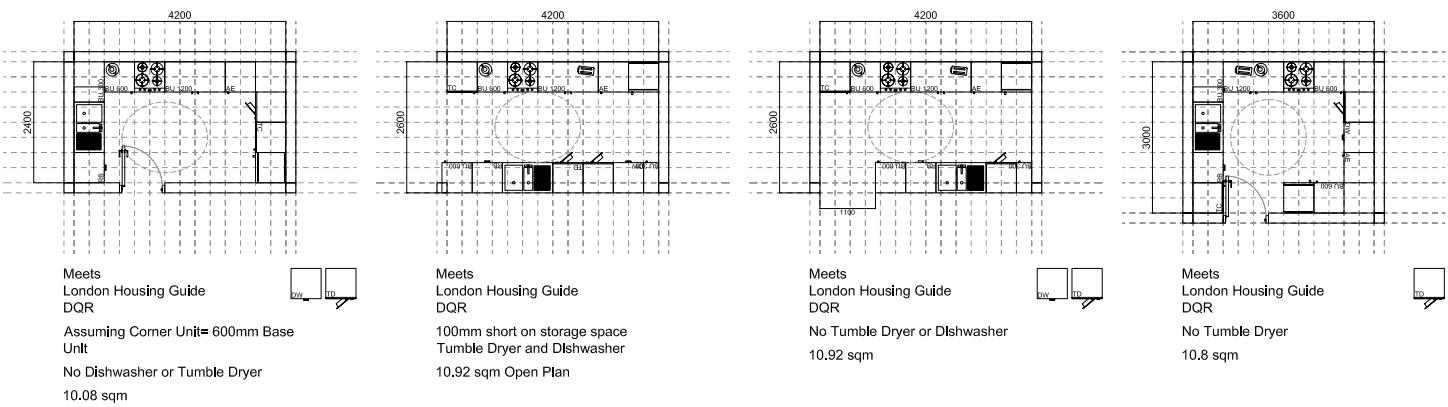
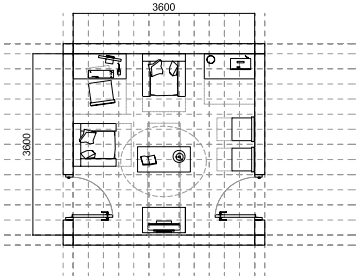
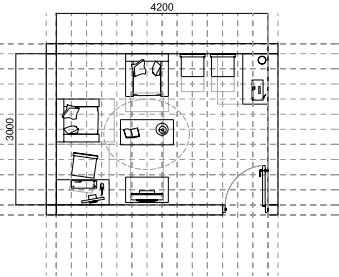


Figure 7.32: KITCHEN ARRANGEMENTS
Scale 1:150

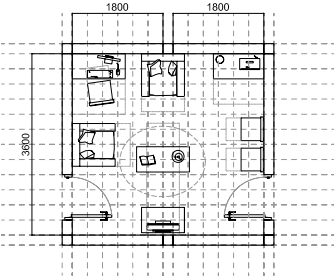
2 PERSON



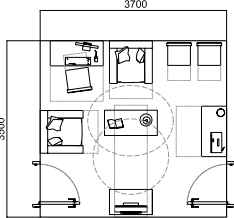
Meets
London Housing Guide
DQR
Beyond permissible spans of ladder
beams
12.9 sqm



Meets
London Housing Guide
Not compliant with DQR
12.6 sqm

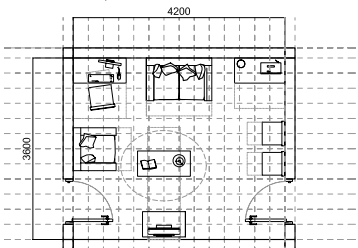


Meets
London Housing Guide
DQR
13.7 sqm

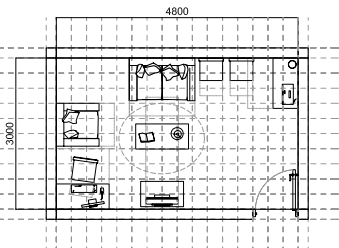


Meets
London Housing Guide
DQR
13 sqm

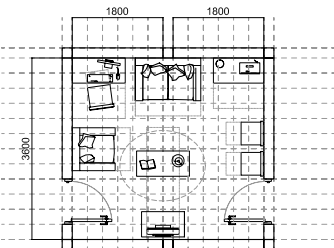
3 PERSON



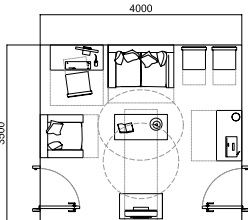
Meets
London Housing Guide
DQR
Beyond permissible spans of ladder
beams
15.1sqm



Meets
London Housing Guide
Not compliant with DQR
14.4 sqm

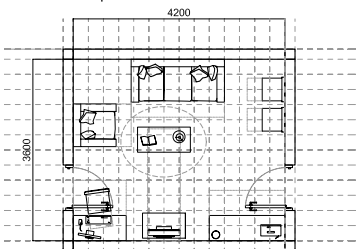


Meets
London Housing Guide
DQR
13.7 sqm

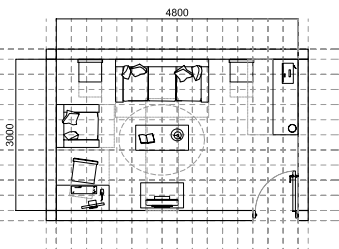


Meets
London Housing Guide
DQR
14 sqm

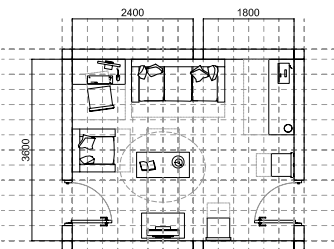
4 PERSON



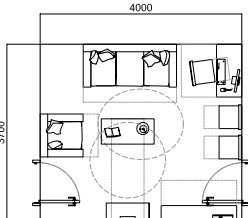
Meets
London Housing Guide
DQR
Beyond permissible spans of ladder
beams
15.1sqm



Meets
London Housing Guide
Not compliant with DQR
14.4 sqm

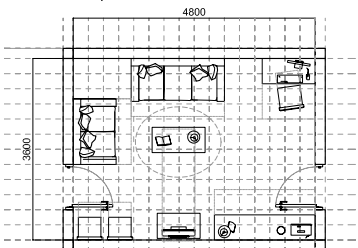


Meets
London Housing Guide
DQR
15.8 sqm

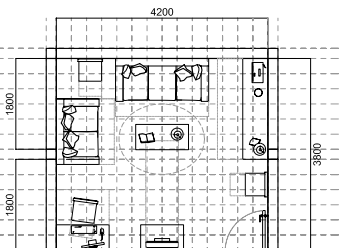


Meets
London Housing Guide
DQR
14.8 sqm

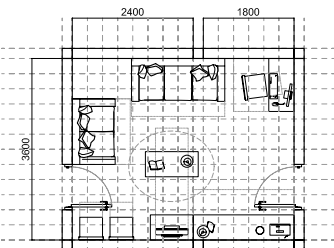
5 PERSON



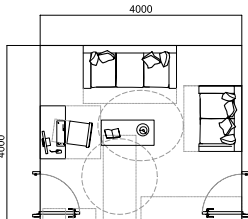
Meets
London Housing Guide
DQR
Beyond permissible spans of ladder
beams
17.3 sqm



Meets
London Housing Guide
DQR
16.0 sqm

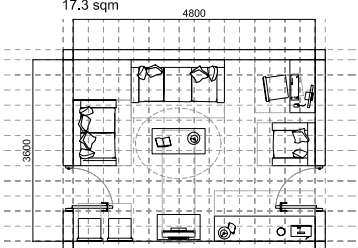


Meets
London Housing Guide
DQR
15.8 sqm

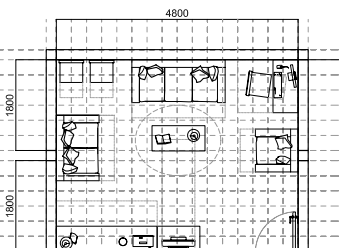


Meets
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DQR
16.0 sqm

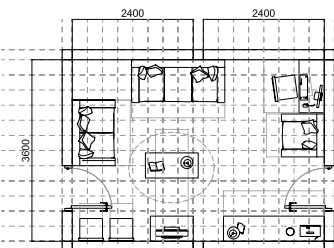
6 PERSON



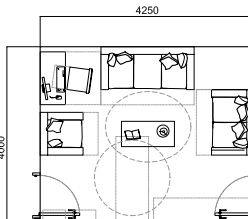
Meets
London Housing Guide
DQR
Beyond permissible spans of ladder
beams
17.3 sqm



Meets
London Housing Guide
DQR
18.2 sqm



Meets
London Housing Guide
DQR
18.0 sqm



Meets
London Housing Guide
DQR
17.0 sqm

Figure 7.33: LIVING ROOM ARRANGEMENTS
Scale 1:150

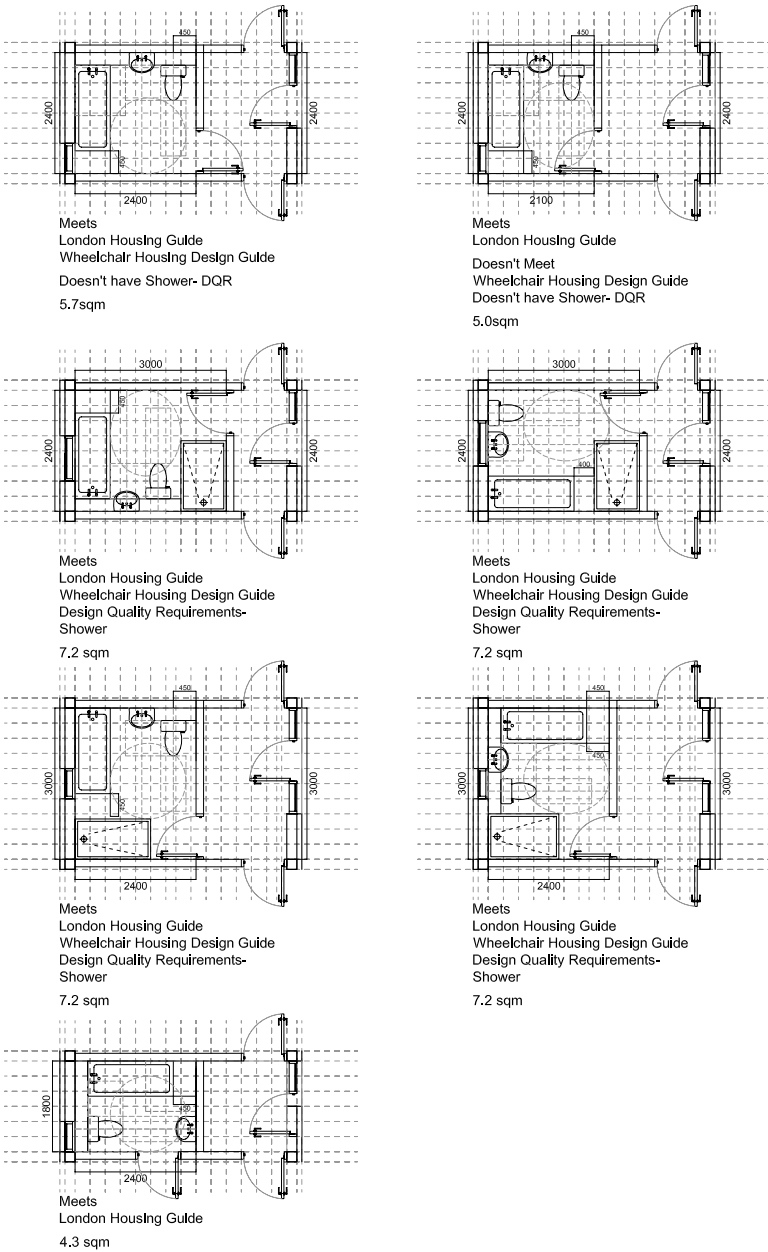


Figure 7.34: BATH ROOM ARRANGEMENTS
Scale 1:150

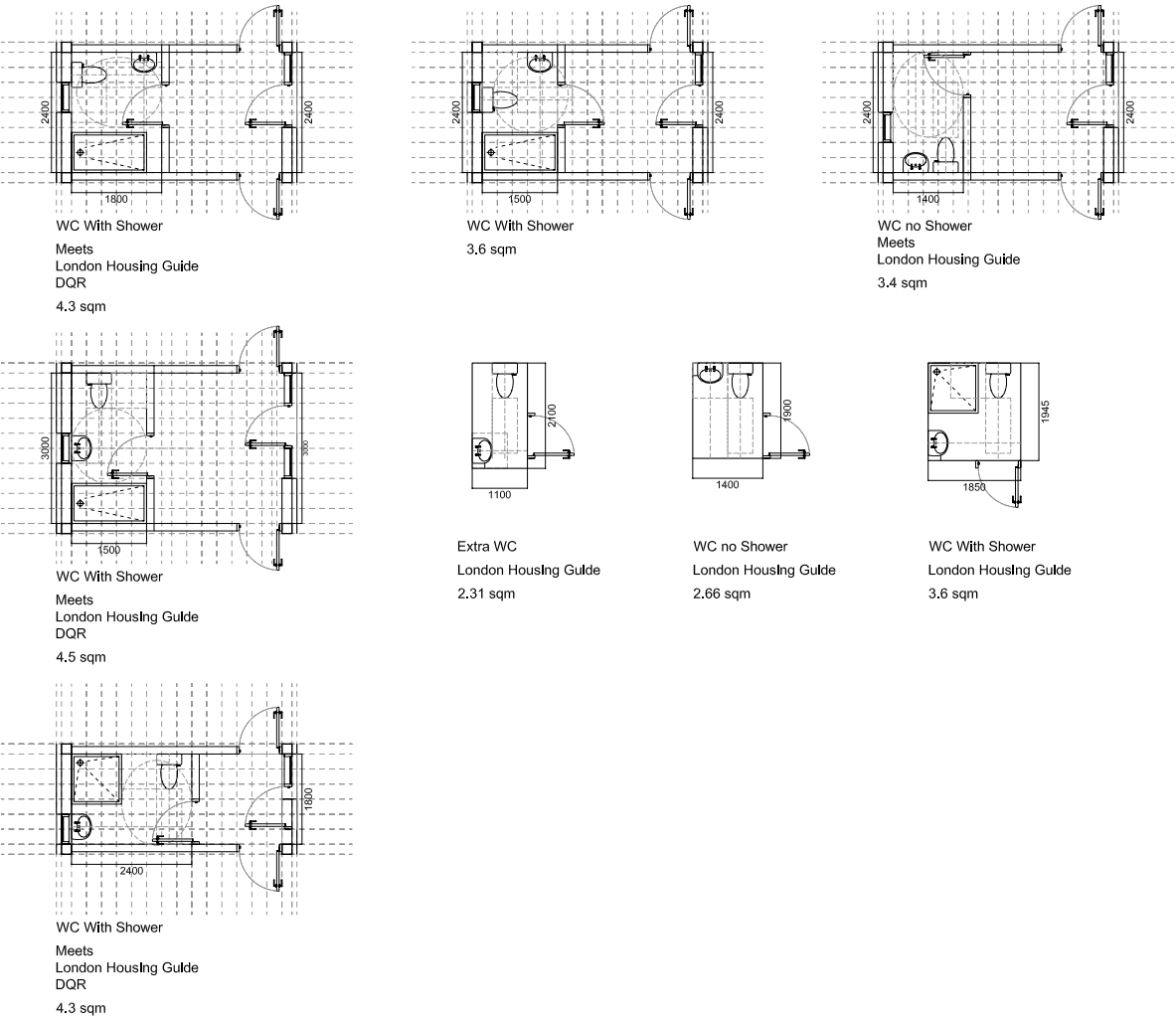


Figure 7.35: WC WITH SHOWER ARRANGEMENTS
Scale 1:150

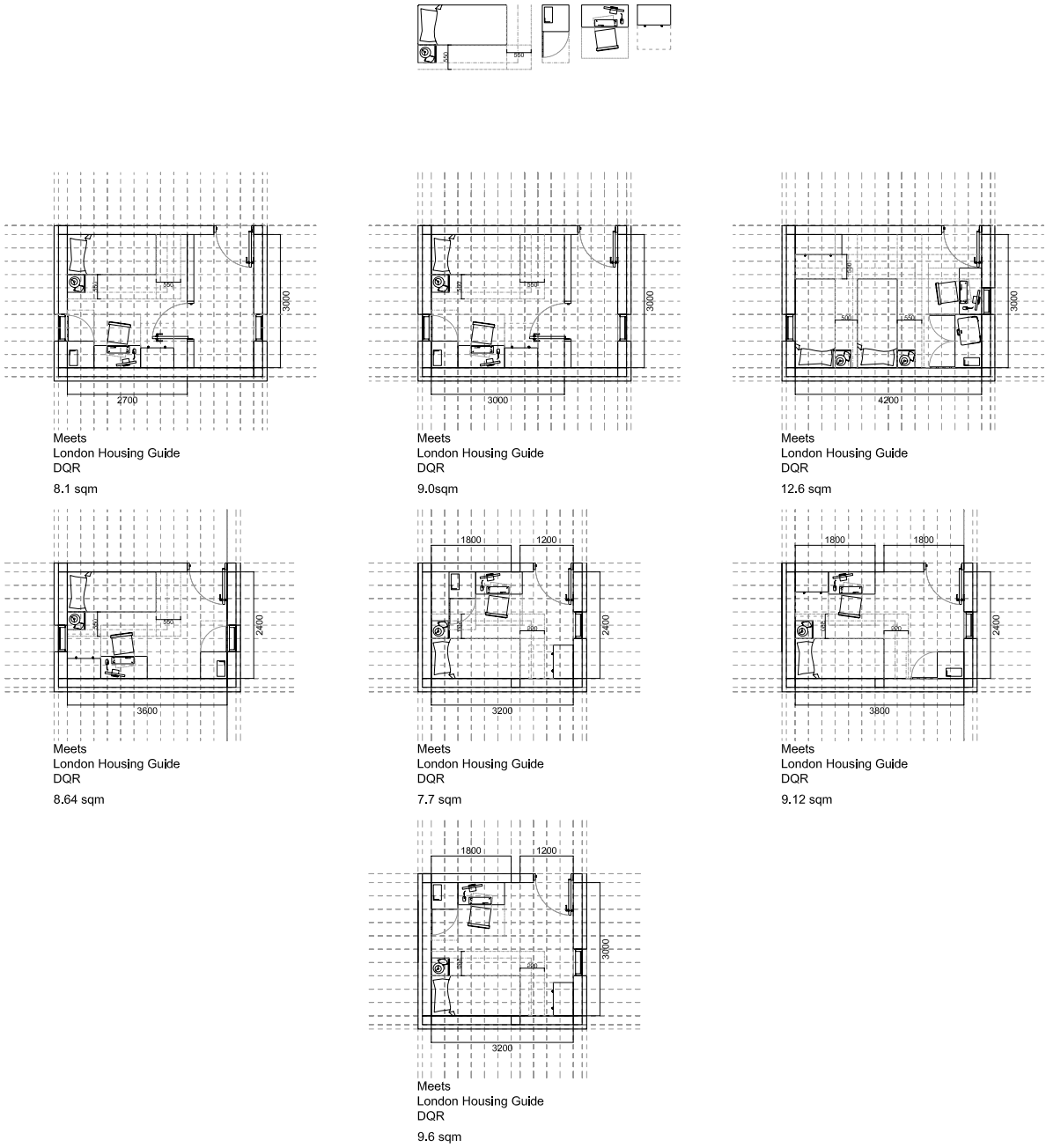


Figure 7.37: SINGLE BEDROOM ARRANGEMENTS
Scale 1:150

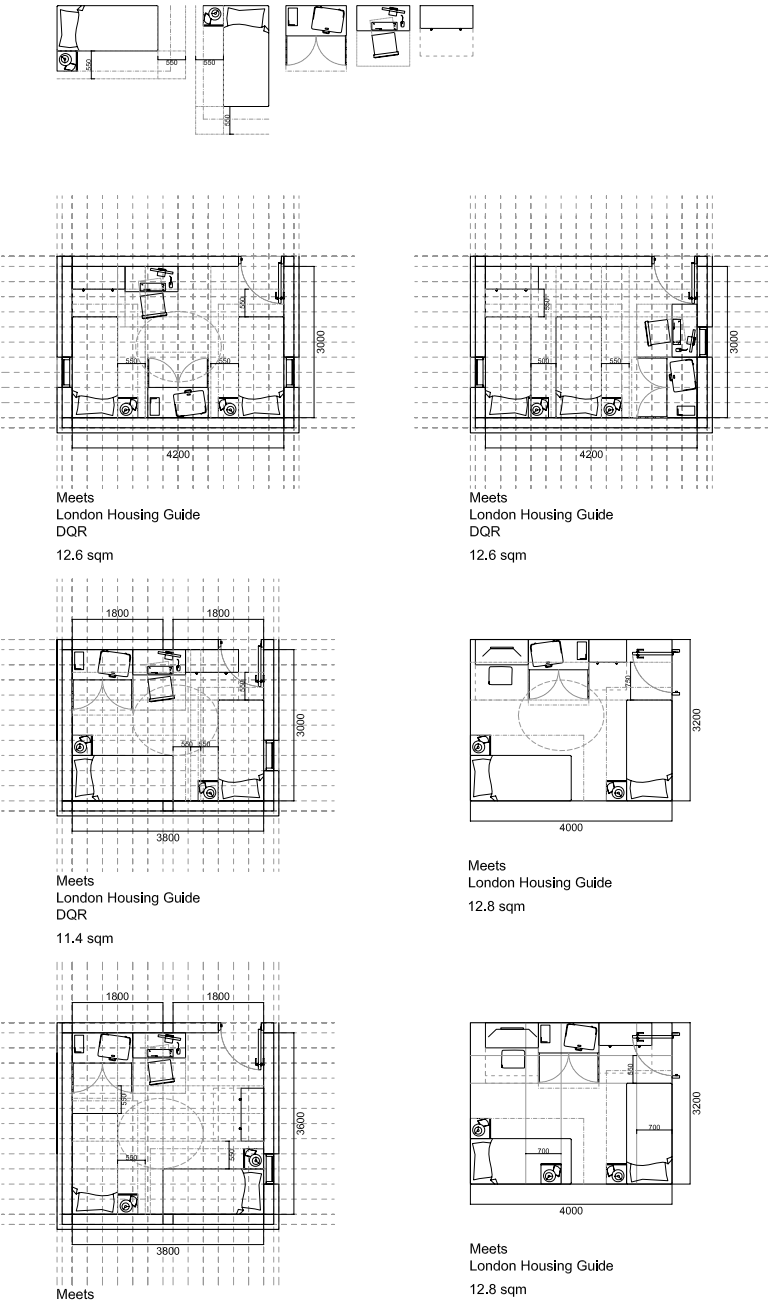


Figure 7.36: TWIN BEDROOM ARRANGEMENTS
Scale 1:150

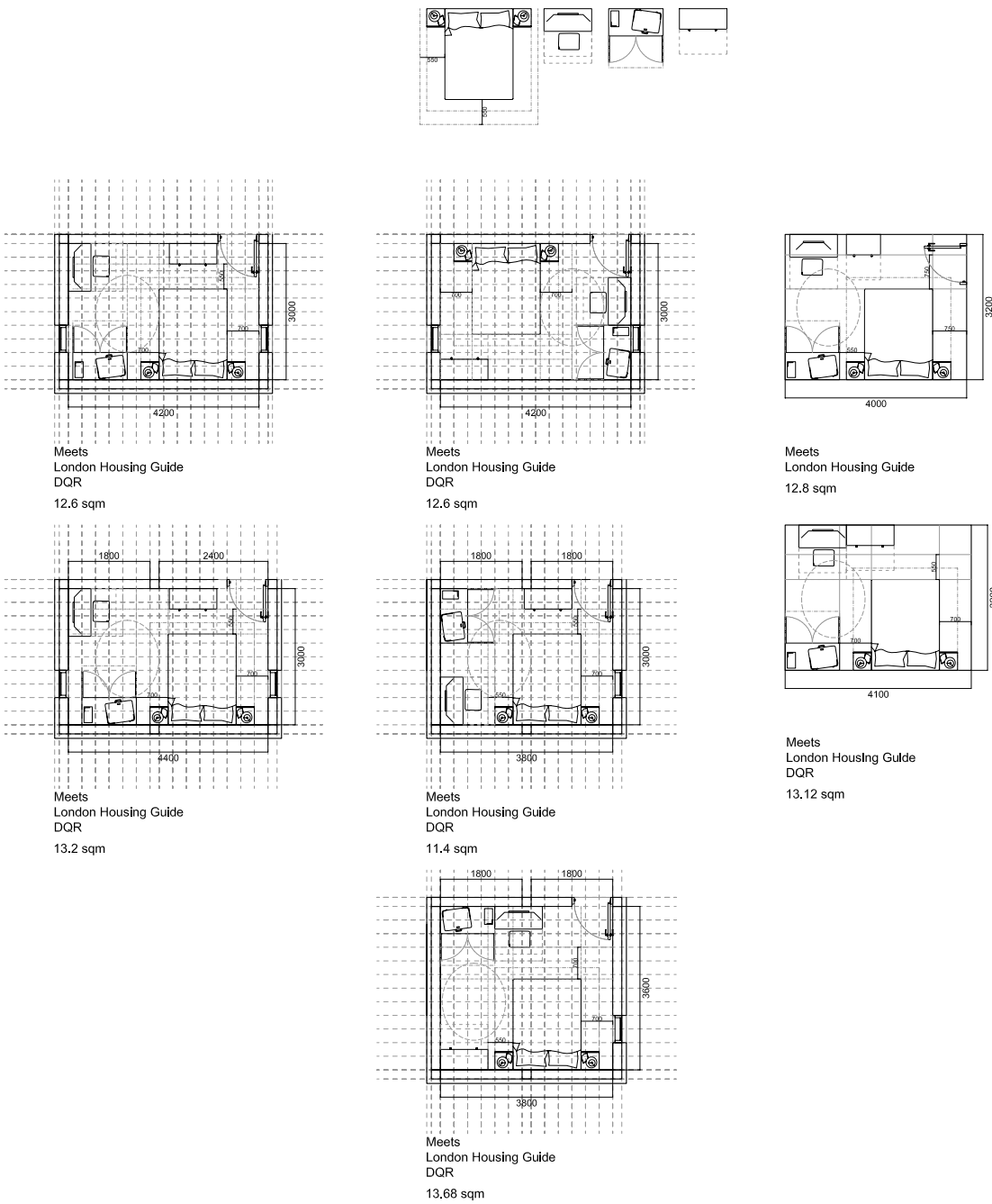


Figure 7.38: DOUBLE BEDROOM ARRANGEMENTS
Scale 1:150

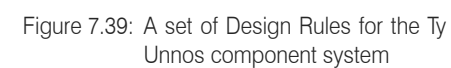
7.03.1 SUMMARY

When applied to domestic rooms types, the proposed 600mm dimensional ‘tartan’ type grid and associated structural arrangement has proved to be generally efficient and appropriate in plan. In section however a 300mm or 450mm may enable a greater flexibility for the positioning of openings. When considering floor to ceiling heights, a 300 or 450mm grid would also meet the LHDG minimum floor to ceiling height of 2.6m.¹³

Generally the permissible span of the primary structural elements, ie the Ty Unnos box section beam, does not appear to be a limiting factor for the design of room types of this scale. However the permissible span of the secondary structural elements, ie the Ty Unnos ladder beams does not provide an efficient or flexible solution for the design of the larger domestic rooms. The proposed 3.1m permissible span is on the cusp of the required spans to achieve comfortably proportioned rooms however an increase in the permissible span of ladder beams to 3.6m or 4.2m would make the system much more accommodating and efficient generally.

13 Mayor of London, *London Housing Design Guide: Draft for Consultation 2009*, p. 55.

- 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.



7.04.1 PRECEDENT STUDY

This research study has adopted the approach that a proposed construction system would be applied in construction by determining the design process from RIBA Stage C - Concept. In this scenario, the proposed construction solution is integrated right from the beginning of the design process enabling the design team to apply the required design rules to the developing proposals. In reality, residential developments are rarely able to develop in this manner. For many projects, construction methods will be decided, at least in detail, following Stage D - Design Development.

Throughout the project concerns have been raised regarding the adaptability of a construction system in the scenario where designs are advanced beyond design development, specifically the application of the system to designs that are the subject of existing planning approvals. Timber panel systems and traditional masonry construction methods adapt well to alternative designs, particularly at the domestic scale. However the need for early integration of advanced construction methods is often a significant barrier to the application of MMC systems.

In order to test the flexibility and adaptability of the system to proposed developments, an initial design study applies the proposed design rules detailed above to a number of recently realised housing precedents. By reinterpreting each proposal in plan, section and elevation the study will test;

- The applicability of a 600mm layout grid, specifically the affect on net and gross floor areas
- The position and size of openings
- The appropriateness of permissible structural spans
- Sectional organisation specifically floor heights and stepped sections
- The adaptability of the structural arrangement, particularly in section.

A set of detailed design drawings can be found in accompanying appendix A1.

Clay Field_ Riches Hawley Mikhail Architects

A development of 26 affordable housing units arranged into 8 terraces on a rural site in Suffolk. The development was awarded the RIBA Award in 2009.



Victoria Avenue_ Design Research Unit Wales

A DQR and Lifetime home compliant social housing development of 3 and 4 bed terraced units.



Figure 7.40: Clay Field_ Riches Hawley Mikhail Architects

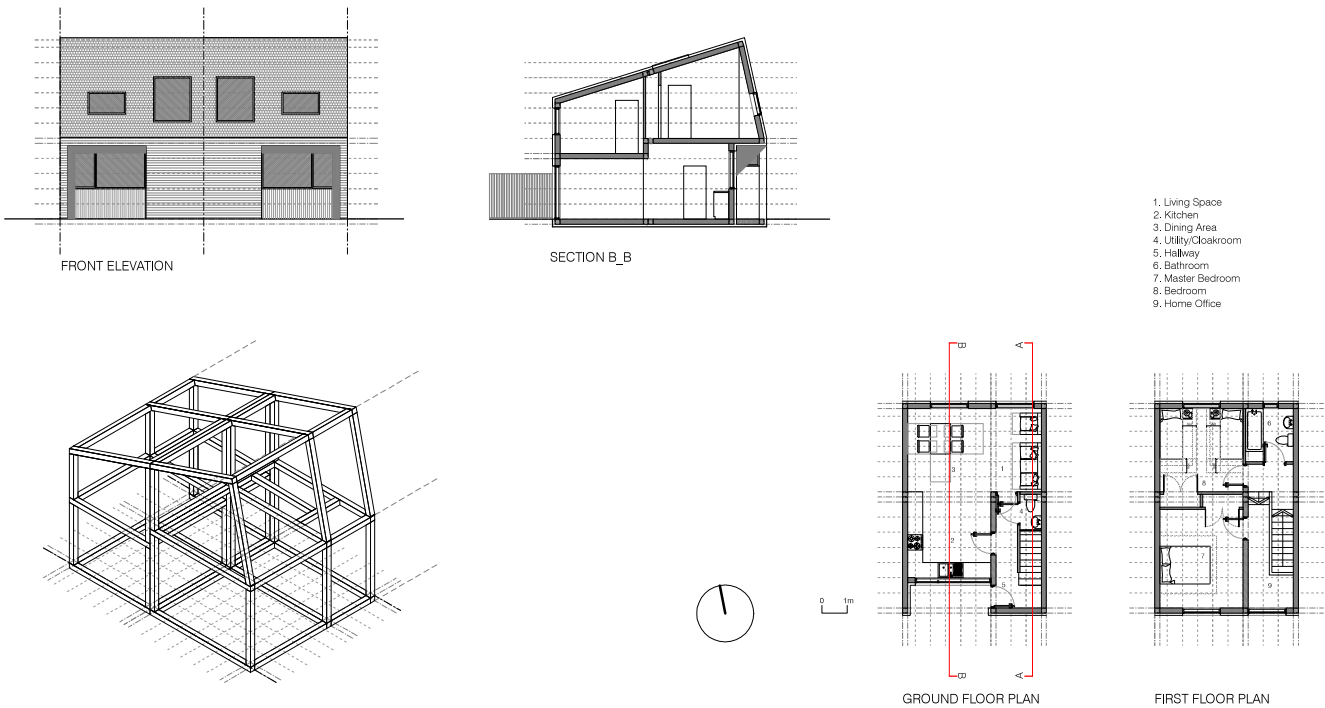
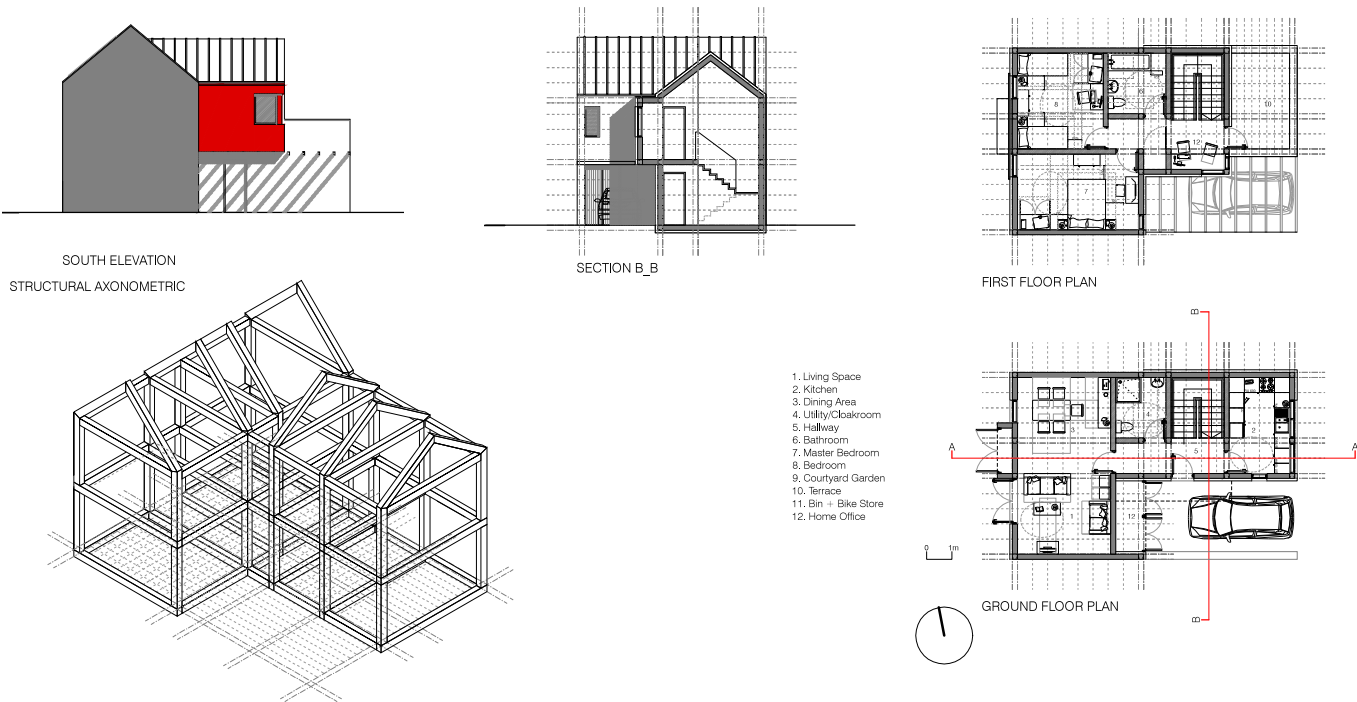


Figure 7.41: Victoria Avenue_ Design Research Unit Wales



Ty Pren_ Feilden Fowles

A detached long house situated in rural Brecon designed to passive design principles. The project has been critically assessed as a highly appropriate precedent for new vernacular housing for the context of rural Wales.



Shingle House_ NORD

A primarily single storey detached house in the shingle landscape of Dungeness. The project was designed with an intent for sensitivity to its surroundings and the local vernacular.



Accordia_ Feilden Clegg Bradley Studios

A private development of 212 houses and 166 apartments widely regarded as a new benchmark for large scale housing in the UK. The project was the first housing project to win the RIBA Stirling Prize in 2008.

OBSERVATIONS

Clay Field_ Riches Hawley Mikhail Architects

Design studies to date have typically considered the primary span direction to be in the short direction. For Clay Field however replicating the stepped first floor and assymetrical pitched roof with low eaves required portal frames to span front to back within the party walls.

The post and beam frame with infill panel arrangement adjusts well to the unusual section proposed by RHMA, as the arrangement allows for a structurally clear roof space. In order to achieve the pitched front elevation efficiently, the upper storey of the elevation constructed as a roof pitch with panels spanning from side to side between portal frames.

Victoria Avenue_ Design Research Unit Wales

The Victoria Avenue scheme demonstrates a considerable issue in the design of a panellised roof system with the proposed arrangement of roof form. The proposal requires two perpendicularly arranged roof pitches meeting at a valley junction. In order to replicate this in the post and beam frame, the pitched portal frames to the front section of the plan span perpendicular to the main body of the terraced house. Although easily realised in primary structure, this becomes a considerable challenge to infill the primary structure with standardised infill panels. Although one roof pitch can be realised from standardised panels the perpendicular roof pitch will require bespoke panels, cut in two axes, posing a potentially challenging and inefficient manufacturing operation. In addition it is

Figure 7.42: Ty Pren_ Feilden Fowles

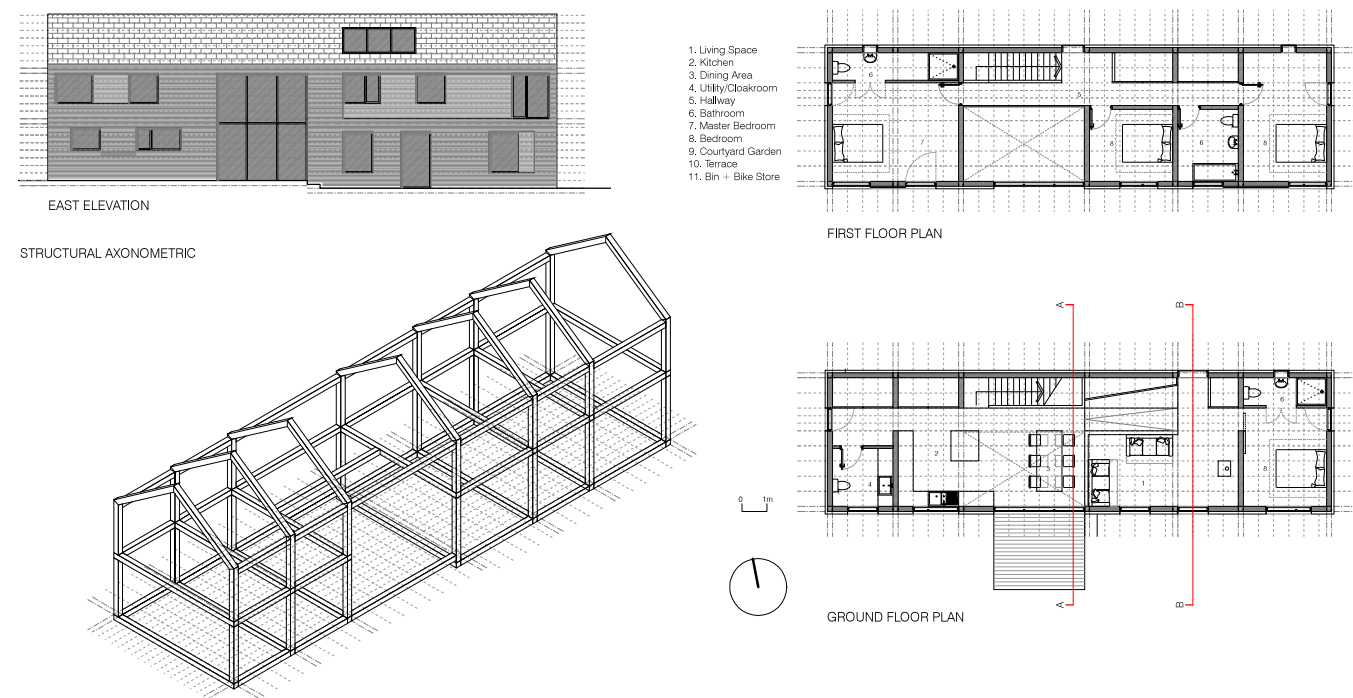
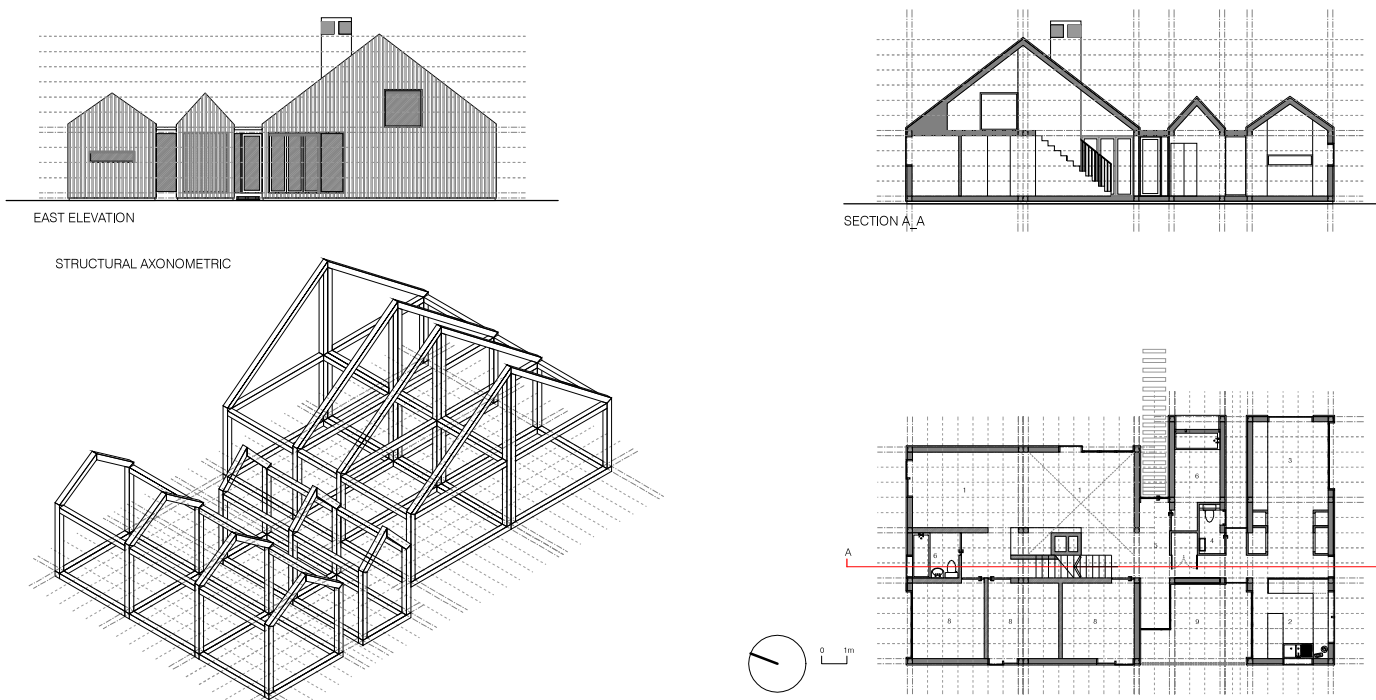


Figure 7.43: Shingle House_ NORD Architects



possible that panels in the main roof pitch will also require additional structural support to enable panels from the perpendicular pitch to bear onto the main roof pitch.

Ty Pren_ Feilden Fowles

Ty Pren in form would appear to be an ideal application for the Ty Unnos system however, many of the dimensions employed challenge the maximum spans of the system components. In both width and length, the proportions of rooms (most notably bedrooms) are typically beyond the current permissible spans of components at 3.3m. These proportions could be replicated by setting out the primary structure to the permissible spans of ladder beams and disassociating internal walls from the primary structure. However this generates a number of conflicts between the resultant positions of the primary structure and the original locations of openings.

The house includes a number of large open plan spaces with associated glazed openings which again challenge the permissible spans of components and require either the interruption of glazed openings with additional structural elements or the inclusion of higher capacity structural elements such as steel lintels.

The stepped and retaining ground floor structure is likely to challenge the efficiency of using the system's proposed suspended timber floor. It would be considerably more efficient in this scenario, to construct a standard ground bearing slab with retaining upstand to provide a base for the post and beam frame above ground.

Shingle House_ NORD

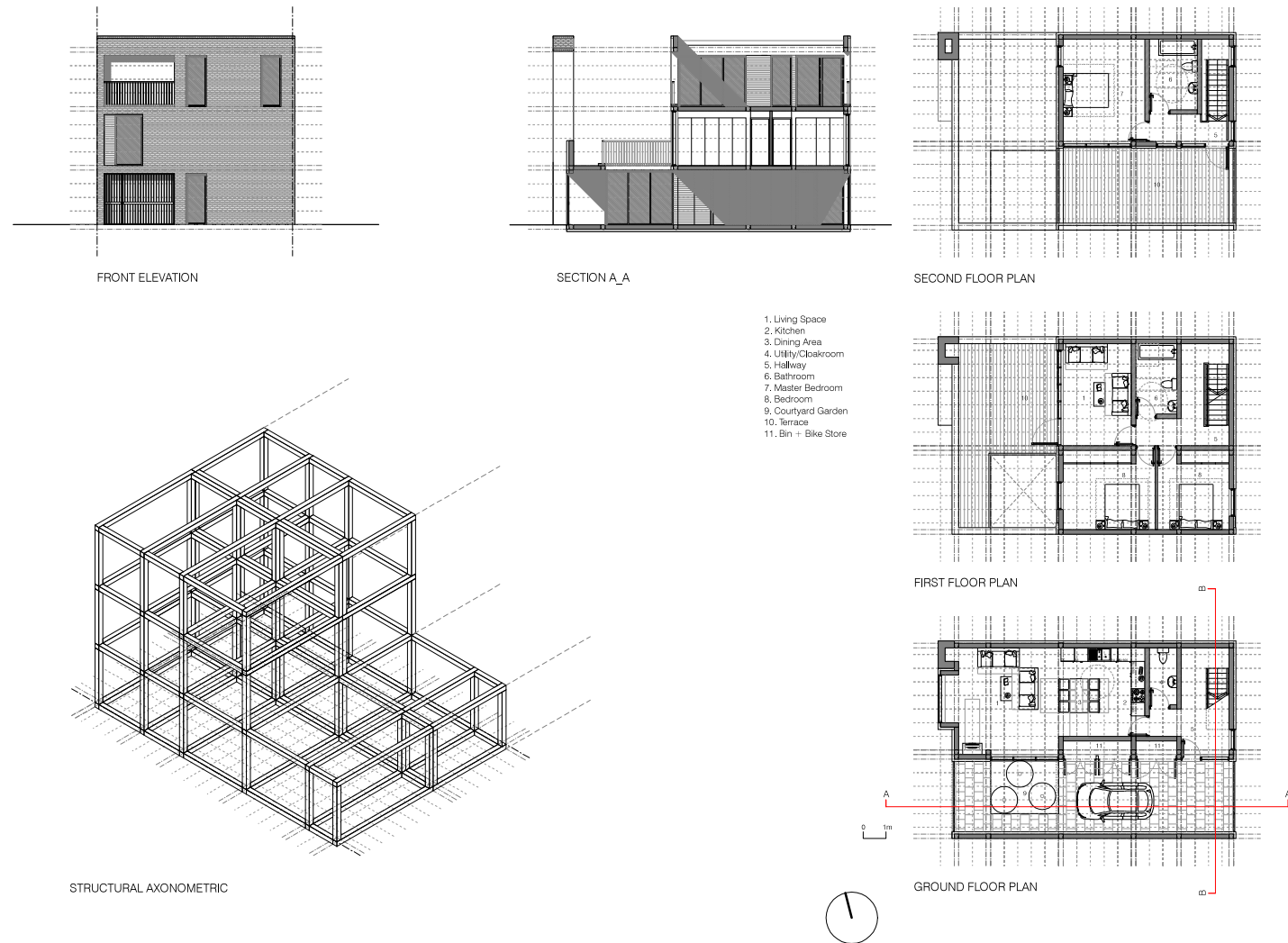
The geometry and form of the Shingle House again would appear to be easily replicable using the post and beam frame arrangement and in the most part the design adapted easily. In order to form the primary open plan living space it has been necessary to expose a single pair of columns centrally, however this is quite neatly integrated into what is originally designed as a large central hearth and chimney.

Accordia_ Feilden Clegg Bradley Studios

The post and beam Ty Unnos frame adapts well to the 3 storey terraced house type. The frame is designed with two primary frames spanning the width of each unit, breaking the plan into two zones with columns buried within the separating wall at each level.

In order to accomodate the car and bedroom zone a portal width of 3.3m has been employed. Once again it was found that a 3.0m dimension is too small for a number of room types, however a 3.6m dimension typically results in excessive floor areas.

Figure 7.44: Accordia_ Fielden Clegg Bradley



GENERAL OBSERVATIONS

In most cases it was necessary to introduce an additional 300mm modular dimension in both plan and elevation. In Clayfields this enabled an efficiently dimensioned porch with entrance door, in Ty Pren this allowed the replication of room dimensions and proportions, and in the Accordia proposal a 300mm dimension is employed to efficiently replicate circulation routes and size of openings. Although increasing the number of standardised components the addition of a 300mm module considerably increases the flexibility and adaptability of the proposed system of components.

The permissive span of the primary structural box beam is generally appropriate for the majority of scenarios in these building types. However the permissive spans of secondary structural ladder beams are a limiting factor in all of these designs. In most cases a dimension just over the ladder beam's capacity of 3.0m is used for rooms such as double bedrooms and living rooms. A number of options are possible to reduce structural spans such as disassociating internal walls from the structural organisation or breaking larger spans into multiple bays of structure however the replication of these design proposals demonstrate the reduced level of flexibility in the positioning of openings if either of these approaches are taken.

7.04.2 PATTERN BOOK STUDY

The culmination of preliminary design studies into space standards and structural and dimensional organisations is the generation of a book of house patterns. These patterns combine design findings with the Performance Specification given in Table 5.12 in order to test the appropriateness of the proposed Design Rules and homegrown timber components for the specific application of affordable housing for rural Wales.

Rural Wales has an incredibly diverse social, economic, geological and climatic landscape. A limited pattern book of standardised house types is not therefore considered to be appropriate for general application across rural Wales. Rather, the Pattern Book is employed as a means to demonstrate the potential opportunity and flexibility for the design of housing. The patterns therefore illustrate a broad range of alternative house forms and types, employing a variety of structural arrangements.

Generally an attempt has been made to tailor the design of the pattern houses to a contemporary interpretation of the vernacular forms and materials of rural Wales. The full set of house plans can be found in Appendix A.

7.04.3 OBSERVATIONS

SPACE STANDARDS

Table 7.9 shows the gross internal floor areas of the proposed pattern book in comparison with the minimum recommended floor areas proposed by the LHDG and Welsh Pattern Book. Five of the proposed layouts are directly comparative with the recommended floor areas. In general however the proposed pattern books floor areas are higher than the recommendations by 15-30% when using compliant room types. These increased floor areas tend to be associated with plans that include increased areas of horizontal and vertical circulation. In the two dormer house types these increased floor areas are exacerbated by the additional floor area required to make allowance for reduced head height on the first floor.

Throughout the pattern book the make up of internal walls has been treated identically to external walls, employing infill panels of the same depth. This results in an increased area dedicated to internal walls. However as the post and beam frame is organised with single columns falling at nodes, there are very few circumstances where columns project into spaces. In addition there are few scenarios where the primary structure becomes a disruptive element in open plan spaces.

FORM

The pattern book demonstrates that the system is adaptive to a broad variety of house forms. The proposed maximum span of 4.8m has resulted in houses often taking the form of relatively long and thin organisations, for example Pattern 1 displayed in Figure 7.45. In these scenarios, smaller room types such as bathrooms and single bedrooms are combined with circulation routes to occupy

Table 7.9: Gross floor areas of 'Pattern Book' house types excluding external walls shown against DQR and LHDG recommended standards.

				Social Housing Standards		
				Pattern Book Range April 2001	Housing Corporation HQI	London Housing Guide
Type	Bed No	Person	Storey			
Flat	1 Bed	2 Person	2	50	45-50	50
Bungalow	1 Bed	2 Person	1	44.8	45-50	50
Flat	2 Bed	3 Person	2	64	57-67	61
Bungalow	2 Bed	3 Person	1	58.1	57-67	61
Bungalow	2 Bed	3 Person	1	58.1	57-67	61
Flat	2 Bed	4 Person	1			70
House	2 Bed	4 Person	2	77.4	67-75	83
Flat	3 Bed	4 Person	1			74
House	3 Bed	4 Person	2	82.7	67-75	86
House	3 Bed	4 Person	2	83.7	67-75	86
Flat	3 Bed	5 Person	1		75-85	86
House	3 Bed	5 Person	2	88.5		96
House	3 Bed	5 Person	2	88.4	82-85	96
House	3 Bed	5 Person	3		85-95	102
Flat	3 Bed	6 Person	1			100
Flat	3 Bed	6 Person	2			100
Flat	4 Bed	5 Person	1			90
House	4 Bed	5 Person	2			100
House	4 Bed	5 Person	3			106
Flat	4 Bed	6 Person	1		85-95	99
House	4 Bed	6 Person	2	103.7	95-100	107
House	4 Bed	6 Person	3		100-105	113
House	4 Bed	7 Person	2	110.9	108-115	6 Pers + 10m2/ Pers
House		7 +			7 Pers + 10m2/Pers	6 Pers + 10m2/ Pers
Flat	5 Bed	8 Person	1		7 Pers + 10m2/Pers	6 Pers + 10m2/ Pers

[illegible]

Figure 7.45: PATTERN 1 - SINGLE STOREY LONGHOUSE

1 Bed 2 Person
47.9 m²

Figure 7.46: PATTERN 2 - SINGLE STOREY LONGHOUSE

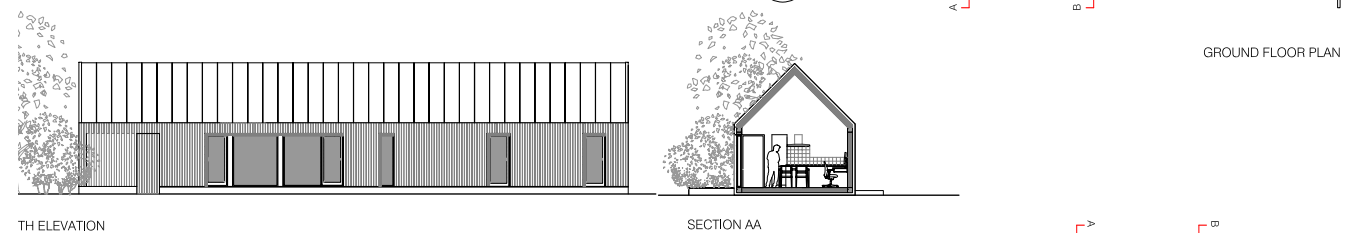
2 Bed 4 Person
75.6 m²

Figure 7.47: PATTERN 3 - SINGLE STOREY SLIPPED PLAN

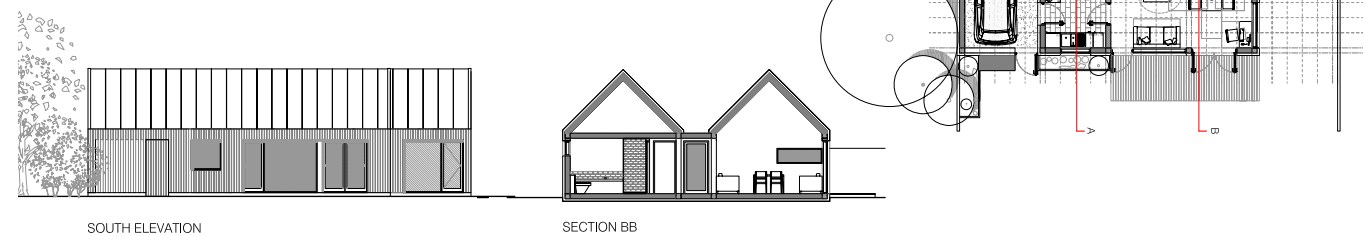
2 Bed 4 Person
80.4 m²

Figure 7.48: PATTERN 4 - SINGLE STOREY COURTYARD HOUSE

2 Bed 4 Person
95.9 m²

the 4.2m or 4.8m wide bays. These single bay deep structures appear to be quite efficient and reflects the Welsh rural vernacular of the 'Longhouse'. The design of the integrated pitched roof structure allows rooms to open up to the roof space, making this arrangement of plan particularly generous spatially whilst maintaining a relatively compact plan form.

The nature of the integrated roof structure which allows an open roof space will provide additional volume to the open plan and closed rooms, making this arrangement of plan particularly generous spatially whilst maintaining a relatively compact plan form.

The design of the box section frame poses a number of design challenges and opportunities when considered in terms of roof form. As previously described, the primary structure is formed from a primary box section frame, organised in a 'portal' fashion incorporating a flat, mono-pitched, or pitched roof rafter, with secondary beams spanning between 'portals'. The initial feasibility study proposed that a range of standardised roof pitches in conjunction with a range of set width modules would enable a choice of roof types whilst ensuring a high level of standardisation.

The generation of room and house types has demonstrated that this approach to house design would be quite limiting and inefficient, resulting in designs that cannot be tailored to the individual needs of sites and occupiers. The approach that I have taken assumes a range of permitted spanning widths arranged on the structural and dimensional grid, ie 600mm increments between 1.2m to 4.8m. This flexibility has the potential to generate a large number of roof forms, particularly when accompanied with complete freedom to determine roof pitch. This is positive from a design point of view, however when considering the efficient standardisation of the post and beam frame and infill panels, this poses a challenging issue. The development of house forms and types has resulted in the conclusion that design flexibility is key to the development of the system and the standardisation of roof pitches in the manner that Utzon employs for the Espansiva system is simply too limiting for general application. An alternative and more inclusive approach would be to introduce a number of bespoke manufactured components that are tailored to each project to allow a good level of design flexibility whilst limiting the number of bespoke elements. Simple and repeatable non structural infill components designed to the required roof angle and geometry at both eaves and ridge, in conjunction with a single panel per roof space which is adjusted to the changing pitch length could be combined with standard, squared infill panels, such as those employed for floors and walls, to complete any roof pitch, see Figure 7.53. These elements will be considered further in the Chapter 8.0.

A frequent characteristic of UK housing, particularly developer housing, is for

Figure 7.49: PATTERN 5 - DORMER STOREY LONGHOUSE

3 Bed 4 Person
64.3 + 56.5 = 120.8 m²

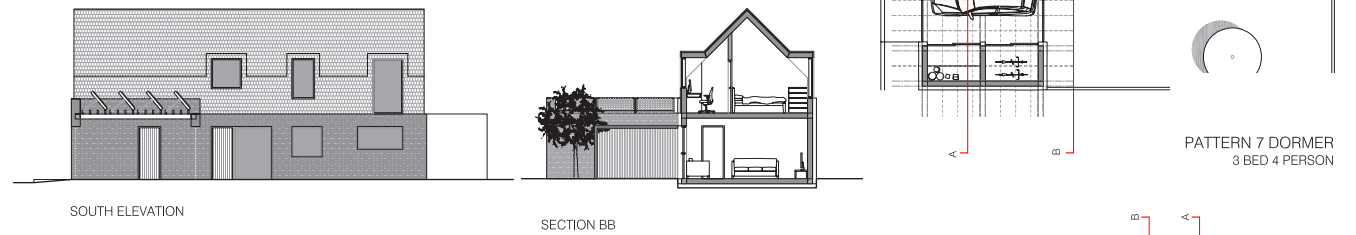


Figure 7.50: PATTERN 6 - DORMER STOREY MEZZANINE

3 Bed 5 Person
90.1 + 35.1 = 125.2 m²

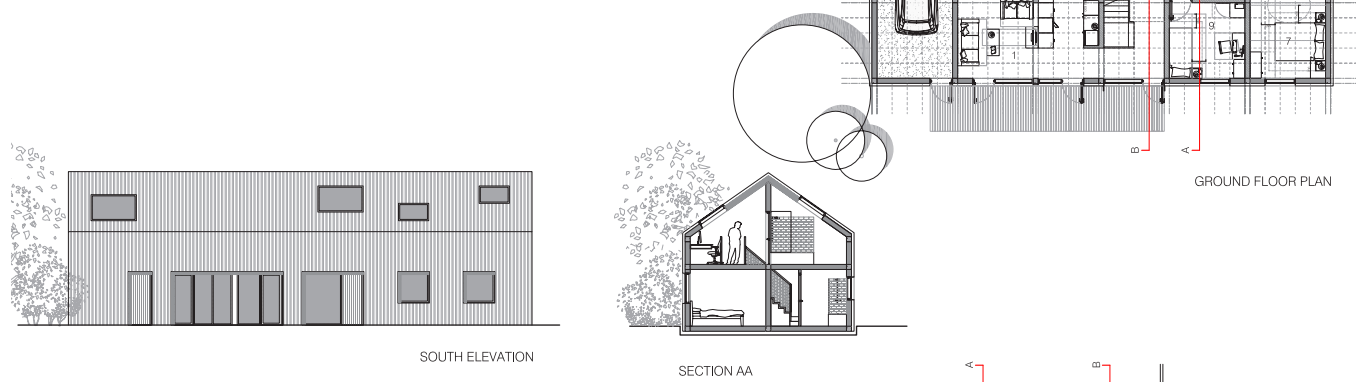


Figure 7.51: PATTERN 7 - TWO STOREY LONGHOUSE

3 Bed 5 Person
56.3 + 52.7 = 109.0 m²

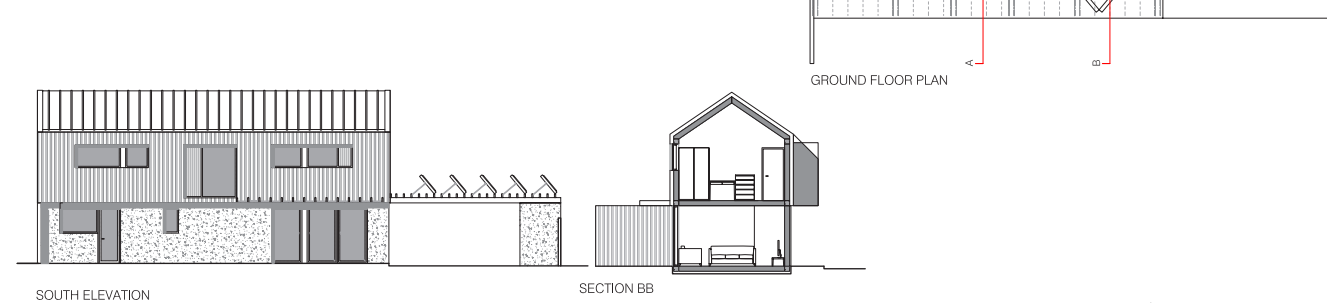


Figure 7.52: PATTERN 8 - TWO STOREY PASSIVE HOUSE

4 Bed 5 Person
63.9 + 65.6 = 129.5 m²

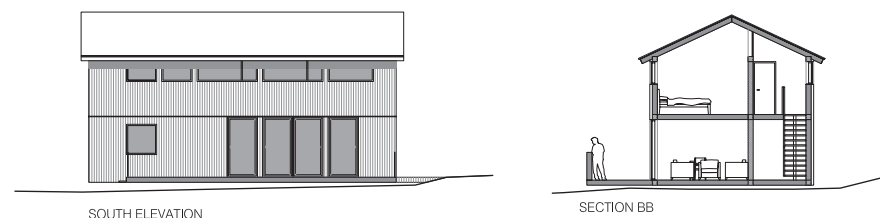


Figure 7.53: Arrangement of roof panels to enable any roof pitch and length.

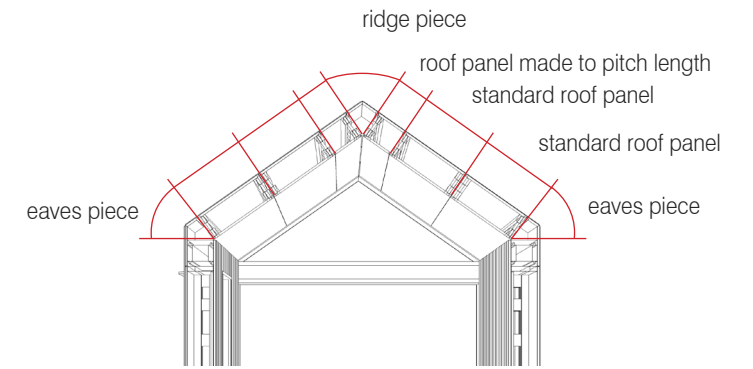


Figure 7.54: Gabled front elevation of a modern developer constructed house.

Source : <http://www.easier.com/75549-taylor-wimpey-to-build-evesham.html>

pitched roofs to meet perpendicularly to one another, typically to result in a gabled front elevation, see Figure 7.54. The use of a panel system as proposed makes this junction particularly challenging with bespoke panels and detailing required for each arrangement of roof pitch. It has been possible to develop a broad range of house geometries without the need for a roof geometry of this type however this is a considerable limitation of the post and beam frame and infill panel arrangement. Pattern 4 demonstrates a layout that would benefit from the roof structure being able to turn a 90° junction. In this case a flat roof circulation zone is employed to separate the perpendicular primary structures with integrated pitches, see figures 7.55 - 56. There does not appear to be an immediate or simple detailing solution to this issue without imposing a restriction on roof pitches and module sizes in order to control the number of scenarios and enable a number of standard infill panels for this junction.

Like many other MMC systems, the Ty Unnos components provide the opportunity to efficiently inhabit the roof space without structural adjustment. Patterns 5 and 6 have therefore been designed with a restricted eaves height and an occupied roof space. In many of the single storey scenarios, Patterns 1 and 2 for example, minor adjustments in section could provide a suitable area within the roof space for habitation with very minimal increase in construction costs.

Fig 7.55: PATTERN 4 - SINGLE STOREY COURTYARD HOUSE
Arrangement of infill panels.

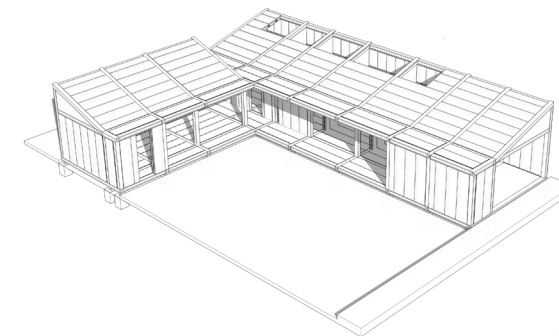


Fig 7.56: PATTERN 4 - SINGLE STOREY COURTYARD HOUSE
Finished built form.

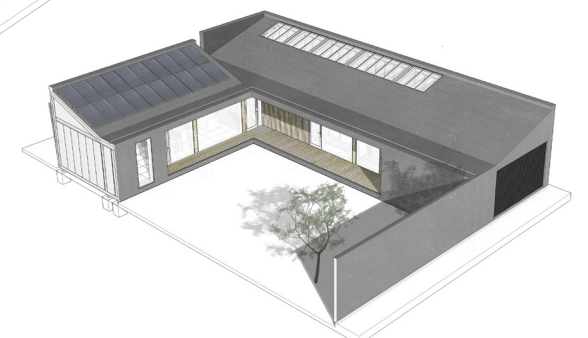


Fig 7.57: PATTERN 9 - TWO STOREY COURTYARD HOUSE

3 Bed 6 Person
94.5 + 18.5 = 113.0 m²

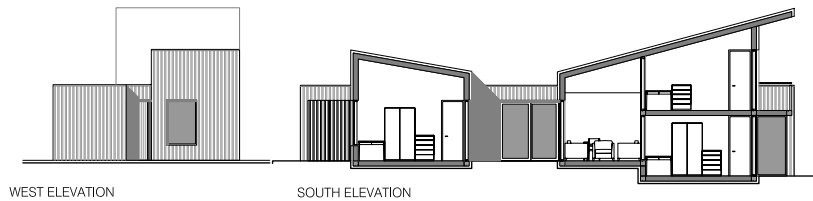
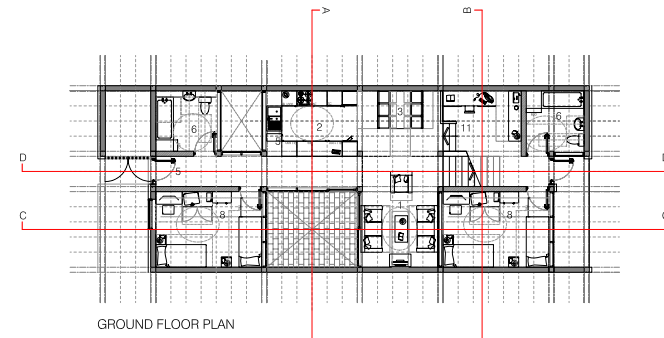


Fig 7.58: PATTERN 10 - MEWS HOUSE

1 Bed 2 Person
56.7 m²
2 Bed 4 Person
49.3 + 32.2 = 81.5 m²

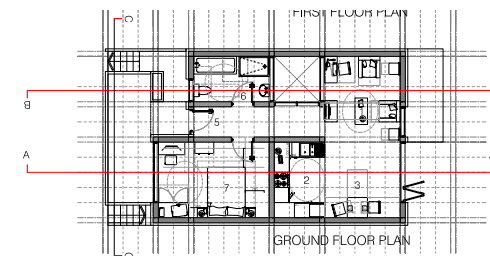
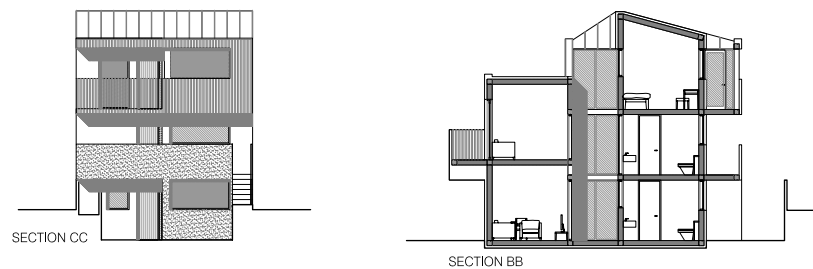


Fig 7.59: PATTERN 11 - WORKERS TERRACE

1 Bed 2 Person
56.7 m²
2 Bed 3 Person
49.3 + 32.2 = 81.5 m²
2 Bed 3 Person
49.3 + 32.2 = 81.5 m²

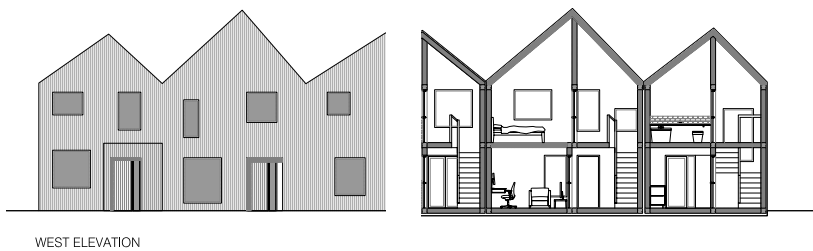
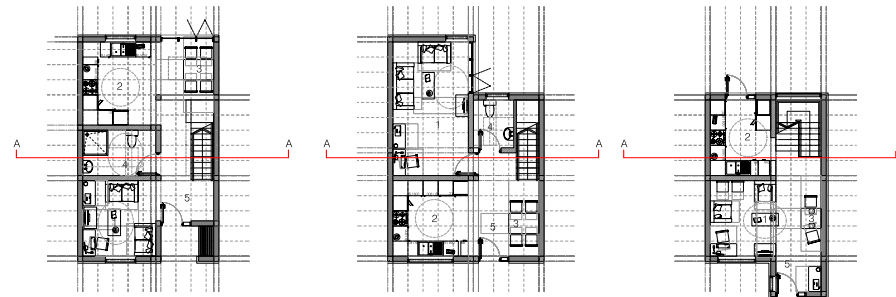
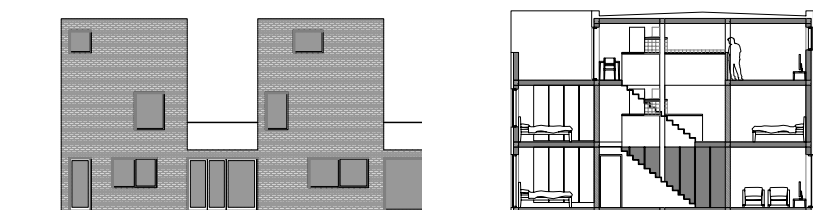


Fig 7.60: PATTERN 12 - LIVE / WORK UNITS

1 Bed 2 Person Flat
45.7 m²
2 Bed 4 Person Maisonette
50.2 + 50.2 = 100.4 m²
2 Bed 4 Person Maisonette
50.2 + 31.5 = 81.7 m²
3 Bed 6 Person Live / Work
50.2 + 46.7 + 31.5 = 128.4 m²



7.04.4 SITE STUDY - TREGYNON

To this point the consideration of homegrown timber components and the design and application of the Pattern Book has been developed with a reasonable detachment from the proposed application and context of affordable housing for rural Wales. Considered from the ideological position of an architect this is particularly uncomfortable. A key responsibility in the development of this study and application is the appropriateness of the findings to this specific and unique context. However the diversity within this application and context has resulted in the appropriateness of the system being defined and assessed for its compliance against a relatively generic performance specification.

With this in mind, from the outset of the research project, a rural site study has been considered as a valuable element in the development and testing of the learning objectives. Although a number of opportunities were explored to identify a 'real' design scenario, either in the form of a multiple unit development for construction or a feasibility type study in conjunction with a rural community, it was not within the scope of this research study to deliver either of these scenarios within the research period. It was therefore determined to focus on the delivery of a single unit in the form of the Ebbw Vale Passive House, which will be considered in Chapter 8.0.

Instead, the site study takes the form of a brief design charette, with clear and limited learning objectives associated with the application of the pattern book to a real and measured rural site;

- To consider the master planning of a challenging rural site including factors such as site densities and the efficiency and adaptability of proposed house patterns at a site scale,
- To identify potential limitations or conflicts with materiality,
- To reflect upon the standardisation and repetition of manufactured elements within a multiple unit development.

THE SITE

The site chosen for this study is the site of the Old Sawmill, Tregynon, the current head office of Coed Cymru. The site is not considered a realistic development opportunity due to the sensitive and valuable nature of the Victorian Sawmill building and its relationship with the Gregynog Estate.

However the site meets many of the criteria required by current planning policy to be considered for Rural Exception Site status. The 0.39 ha site is located on the edge of Tregynon village, a small settlement located 8 miles from Newtown in Powys. Tregynon has undergone considerable development over the last two decades with significant areas of agricultural land developed to



provide predominantly open market housing. Although formal housing needs assessments are not currently available, it is considered that there remains a demand for affordable housing within the area.

The site will be considered in more detail in Chapter 9.0 and the associated Appendix C1 as it also provides the location of the Tregynon Rural Studio construction study.

SITE DENSITY

The site has an area of 0.39 ha, approximately 3,900 m². It is predominantly laid to hardstanding with tarmacadam surrounding the centrally located detached building. To the north-west of the site boundary, the landscape drops quickly to meet a narrow fast flowing brook called the Brecon and to the south-east the landscape is steeply banked up to the private access drive to Gregynog Hall. The site area is significantly reduced by a dense mix of large mature deciduous and coniferous trees and shrubs.

As a rural site, a relatively low density development of approximately 25 units per hectare is considered appropriate to the context. Based on a site area of 0.39 hectares, 25 units per hectare would equate to a target number of 10 units on this site.

OPPOSITE PAGE

Figure 7.61: Wide view of the site from the south east corner.
Figure 7.62: View of the Sawmill from the south east.
Figure 7.63: View of the Sawmill from north west entrance to the site.
Figure 7.64: Satellite photograph of the site.
Source : <<http://www.google.earth.co.uk>> [accessed 7 March 2012]



THE PROPOSAL

The proposal includes a mixture of housing types adapted from the Pattern Book including a terrace of 4 compact two storey houses, a terrace of 4 single storey courtyard houses and 3 detached units. This equates to a density of 28 units per hectare and designates considerable area to existing and proposed vegetation and landscaping and provision for support structures such as a community energy centre and storage for bicycles and refuse.

The proposal is approached as a traditional farmstead, embracing a level of organic variety, with housing taking a number of forms and materiality. A central pedestrian spine crosses the site from north east to south west following the natural path of the existing brook, steadily inclining up the natural slope to the south. The placing and form of units responds to the existing mature vegetation lining the boundaries of the site, with adjustments in sectional arrangements designed to follow the natural contours of the site. Protected south facing courtyards and private gardens encourage the encroachment of natural light into the primary living spaces. These are predominantly arranged east to west with generous south facing openings, encouraging a passive solar design approach. South facing roof pitches provide appropriate areas for renewable technology. At the heart of the scheme a generous area of green space is given over to community use, providing areas for play, cultivation and community activities.

Further drawings can be found in Appendix A3.



OPPOSITE PAGE

Figure 7.65: Axonometric of the Tregynon site proposal.

The rural vernacular form of the traditional Welsh Longhouse is clearly reflected as a theme throughout the scheme, defining a number of detached two storey houses and giving definition to the primary living spaces of a terrace of courtyard houses. Inspiration for a limited palette of materials is also taken from the local vernacular agricultural context. Lightweight, low cost and durable claddings of dark charred timber and pressed metal corrugates are applied to walls and roofs, simply detailed with descreet eaves and rainwater goods, and flush mounted openings. A skin of brickwork is applied to the tree lined pedestrian avenue, providing a robust surface to the floors and walls of the main community areas, encouraging a unity between the independent elements of the scheme.

OBSERVATIONS

The application of a dimensional and structural grid has resulted in house patterns with simple perpendicular geometry. The use of non- perpendicular or curved walls can not be efficiently accommodated within a system of standardised components. When considered as single detached or semi detached units, it is relatively easy to place and adapt the building form to the organic nature of the existing site and vegetation. However, this becomes considerably more restricted when designing with multiple units, and results in a master planning process which is much more imposing than traditional construction methods can offer. In the context of the Tregynon site study, the organisational grid applied to individual patterns is expanded across the site with units and connections placed within this rigid organisation. However, with the use of the 600mm module and the range of available room types, there remains a reasonable flexibility in the scale and geometry of potential units, which in turn allows a reasonably sensitive response to the site. Plans are able to expand or reduce in scale to reflect the mature vegetation on the site making the proposed system more adaptable than some alternative forms of MMC.

The proposal has been approached with the assumption that ground floors are detailed to achieve a level or nearly level threshold detail in accordance with Building Regs and NHBC Standards. It is necessary to assume this detail as the raising of the suspended ground floor to ensure that all structural timber is above 150mm from external ground level (in accordance with NHBC Standards) is entirely prohibitive when considered on a development site. In order to meet this requirement sufficiently in a ramp form, the resultant length of ramp would be in the region of 5-6m, which when considered in a site context, is entirely unfeasible. The use of a suspended ground floor structure, and level threshold detail makes a multiple unit development considerably more complex to achieve than the construction of a traditional ground floor slab.

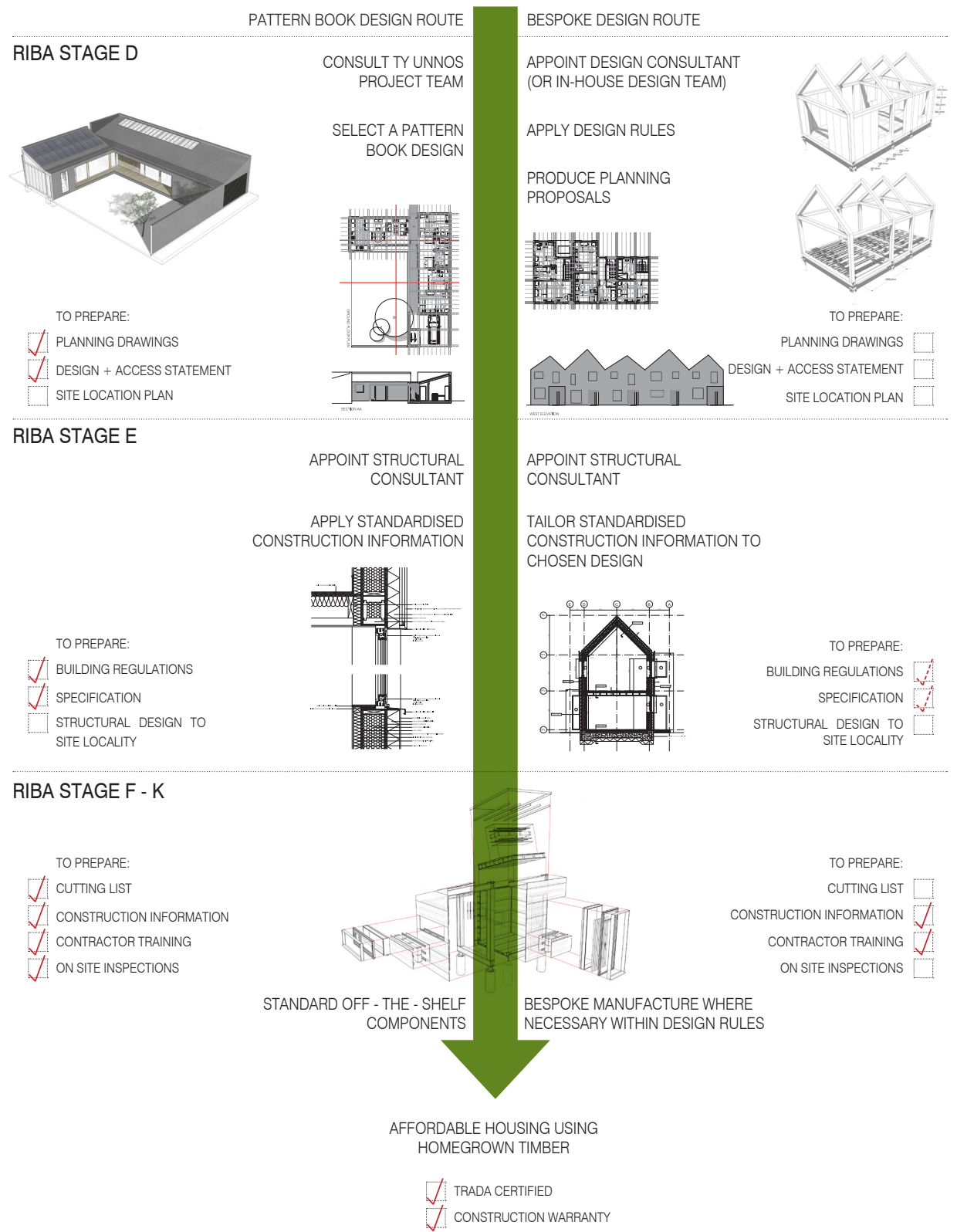
Although a number of alternative house forms are proposed, and generally the proposal offers a good level of variation, there is a very high potential for repetition

and standardisation of prefabricated components. A number of design factors have been consciously applied to encourage this result;

- All roofs are either flat or pitched with a 40° angle.
- All ground floor and first floor rooms maintain a floor to ceiling height of 2.4m.
- Window and doors are consistent throughout, with a head height of 2.1m, and adhered to a 600mm dimensional grid in plan, and could be standardised further if desired.
- The majority of units employ a 4.2m span to the primary living rooms and bedrooms.

These factors result in the majority of infill panels manufactured to a 600mm width by 600mm increments in length from 0.6m to 3.0m, and a large number of repeated frame components including connectors.

At this level of detail, the study does not explicitly consider the detailed application of finishing materials in conjunction with the proposed construction methods however it enables the consideration of design potential, and in this context it has not revealed any concerns or limitations. Lightweight materials have been encouraged throughout as they are deemed highly appropriate to local skills and resources and the context of this area of rural Wales. The application of red brick to the main pedestrian avenue is a clear divergence from this approach and will inevitably result in an alternative set of construction details, most likely including solid mass foundations, and an entirely different set of construction skills. Its application however is likely to result in a greater level of acceptance from the general public and occupiers, to whom masonry construction remains a symbol of good and durable construction practice. If considered as a community self build, this element of the proposal, most likely to be realised last, and employed in an entirely autonomous and non-essential application, would complete a full set of generally applicable construction skills and experience.



7.05 SUMMARY OF FINDINGS

Based on these design studies, it has been possible to summarise the following findings;

- The 600mm dimensionally coordinated organisation has enabled a good level of flexibility, particularly in plan arrangement.
- The addition of a 300mm dimension would make the system considerably more efficient and flexible to room design. This is particularly relevant in section, where a 300mm dimension would enable a much greater range of opening sizes.
- The Pattern Book of House Types has resulted in larger than recommended properties. This does not however necessarily result in a reduced economic efficiency as there is potential for economies of scale to alter the economy of system builds.
- The maximum permissible span of 3.0m for ladder beams is a critical constraint on design. As the position of the primary structure is associated with the placement of internal walls, rooms are not able to achieve the required geometries for DQR and LHDG compliant room types. The study has thus far offered a number of solutions, however it can be concluded that the secondary structural ladder beam needs further development to enable an increased span. This should be more in line with the capacities of alternative spanning members such as JJI Joists and PosiJoists. A recommended target dimension would be 3.6 metres however an increase to just 3.3m would significantly increase its applicability.
- For site applications, the proposed system of homegrown timber components would appear highly appropriate to the specific requirements for housing for rural Wales. The Tregynon design study has illustrated that the structural and construction arrangement can be applied efficiently at this scale and density of construction. Additionally, the proposed arrangement of components has enabled an adaptable and flexible system which when applied to site contexts, can facilitate a wide range of appropriate design solutions.
- The Pattern Book of House Types illustrates a small selection of the design potential enabled through the application of the proposed Design Rules. The designs illustrate a definite appropriateness to the rural context. The system would appear to deliver its greatest potential when considered as low density detached or semi detached dwellings however a selection of patterns have been proposed for higher density situations.
- Material and design aesthetics will be tested further through prototypical studies, but in considering the design of house patterns, the proposed

Figure 7.66: Alternative procurement options offered by the Ty Unnos system build.

system has great design potential and suitability for rural housing applications, in terms of form and materiality. The proposed structural arrangement enables the system to be entirely atectonic, ie the primary construction can be disguised internally and externally with an unlimited opportunity for material finishes. Alternatively, the system has great potential for tectonic expression in the completed construction, particularly in the design of its internal spaces. As a strict approach has been taken to the dimensional and structural arrangement of the system, there is the opportunity to positively express the primary construction elements.

- As with typical timber frame construction, the system can be used in conjunction with any form of external cladding. It is proposed that the system can efficiently employ lightweight point footings, therefore lightweight claddings will offer distinct benefits over masonry claddings however this is not restricted, and there remains the opportunity to combine the lightweight structure with a non-structural masonry cladding.

Chapter 8.0

Prototypical Studies

a series of case study construction projects

PERFORMANCE CRITERIA	STANDARD	PROTOTYPICAL STUDIES			
		LLANDEGLA FOREST VISITOR CENTRE, COED LLANDEGLA	ENVIRONMENTAL RESOURCE CENTRE, EBBW VALE	WELSH PAVILION, SMITHSONIAN FOLKLIFE FESTIVAL	WELSH PASSIVE HOUSE, EBBW VALE
COMPONENT DESIGN AND CERTIFICATION					
STRUCTURAL ORGANISATION	Portalised Structure				
	Post and Beam Frame				
	Single Storey				
	Multi Storey				
COMPONENT PERFORMANCE	Box Section Frame				
	Threaded Rod Connector				
	Solid Section Connector				
	Ladder 1 _ Solid Flange				
	Ladder 2_ Nail Laminate				
BUILDING DESIGN					
SPACE AND QUALITY	Space Standards				
	Lifetime Homes				
DESIGN FLEXIBILITY	Form				
	Scale				
	Organisation				
	Materials				
	Openings				
'DELIGHT"					
DETAILED DESIGN					
CONSTRUCTION ELEMENTS	Sub Structure	CONCRETE PILE	TRENCH FOOTINGS		GROUND BEARING RAFT
	Structure - Primary	PORTAL FRAME	PORTAL FRAME		POST + BEAM 2 STOREY
	Structure - Secondary			LADDER BASED PANEL	SOLID STUD INFILL
	Thermal Envelope		SIPS INFILL PANELS		BLOWN WARMCEL
	Services				
DIMENSIONAL COORDINATION	Organisation				
	Scale & Weight of Components				
	Standardisation				
WARRANTY & NATIONAL STANDARDS	Planning Approvals				
	Building Regulations				
	National House Building Council				
ENVIRONMENTAL PERFORMANCE	Thermal Performance				
	Airtightness				
	Code for Sustainable Homes				
	PassivHaus				
MANUFACTURE					
A S S E M B L Y METHOD	Low Technology Assembly				
	Semi- Automised				
	High Craft / Bespoke Assembly				
SUPPLY CHAIN					
CONSTRUCTION / BUILDABILITY					
CONSTRUCTION SKILL TYPE	Low Skill / Self Build				
	High Skill / Specialist				
	'General' Contractor				
REFLECTION					
ECONOMIC PROFILE					
OCCUPATION RESPONSE					

8.01 INTRODUCTION

Since the publication of the Ty Unnos feasibility study the Project Team have embarked upon a series of ‘real’ design projects in order to test, develop and refine the Ty Unnos system. In the following chapter, four prototypical studies will be described and analysed against research outcomes as identified in the Development Framework, shown in Table 8.1.

The first of these projects to gain planning approval was an Environmental Resource Classroom at Ebbw Vale for Blaenau Gwent County Borough Council, which combined homegrown Ty Unnos frames with SIPS panels and was completed in May 2010. This was designed in parallel with a Visitor Centre for forest management company UPM Tilhill and Forestry Commission Wales at Coed Llandegla, near Wrexham, which received planning permission in June 2008, but faltered later that year due to funding issues.

A number of temporary buildings have been assembled using the Ty Unnos system during the research period. These have been displayed at a number of events across Wales. The most notable of these is the Ty Unnos Pavilion for the Welsh Festival at the Smithsonian Institute in Washington DC.

The first housing pilot project was delivered on behalf of Blaenau Gwent County Borough Council, again on the site of the former Ebbw Vale Steelworks, as part of the ‘Future Works’ housing site.

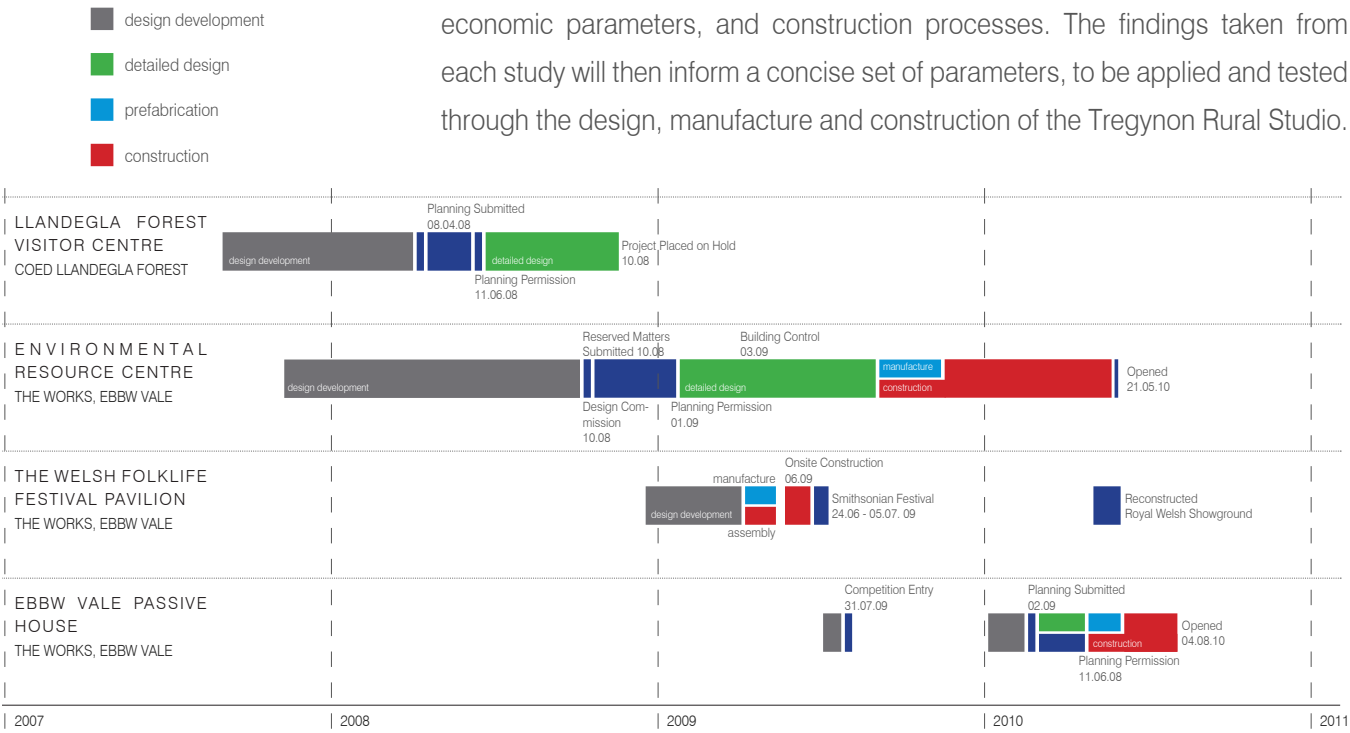
As detailed in the methodology, each prototypical study has been approached with a number of identified research outcomes as set out in the Development Framework. Design considerations such as space standards, environmental performance and dimensional coordination have been tested along with economic parameters, and construction processes. The findings taken from each study will then inform a concise set of parameters, to be applied and tested through the design, manufacture and construction of the Tregynon Rural Studio.

PREVIOUS PAGE

Table 8.1: Matrix of development objectives

THIS PAGE

Chart 8.1: Programme of development for the prototypical studies.



8.02 LLANDEGLA FOREST VISITOR CENTRE
COED LLANDEGLA FOREST, WREXHAM

PROJECT SUMMARY

Architect Design Research Unit Wales
Client UPM Tilhill
Main Contractor Not Appointed
Manufacturer Cowley Timberwork
Completed On Hold
Value £250 000
Contributions include
concept and site studies, planning
application support, presentation
images and modelling, detailed design,
client and design team communication.



Coed Llandegla Forest covers 650 hectares and is one of the largest privately owned recreation facilities in North Wales. It is also the first privately owned forest in Wales to be recognised as a source of sustainable timber and to carry the Forest Stewardship Council logo. It grows at a rate that allows the harvesting of 7,000 m³ of timber per year.

Llandegla Forest Visitor Centre was constructed in 2004 as a centre for mountain biking. An existing log on log cabin houses cafe facilities, a cycle shop, workshop and hire shop, toilet facilities and a classroom. The Cabin and car park act as a base for a network of mountain biking trails and hiking routes through the surrounding woodland. Since its construction, the Centre's reputation has rapidly grown and established itself as one of the leading biking centres in Wales. This reputation now draws upwards of 600 cyclists a day at peak periods.

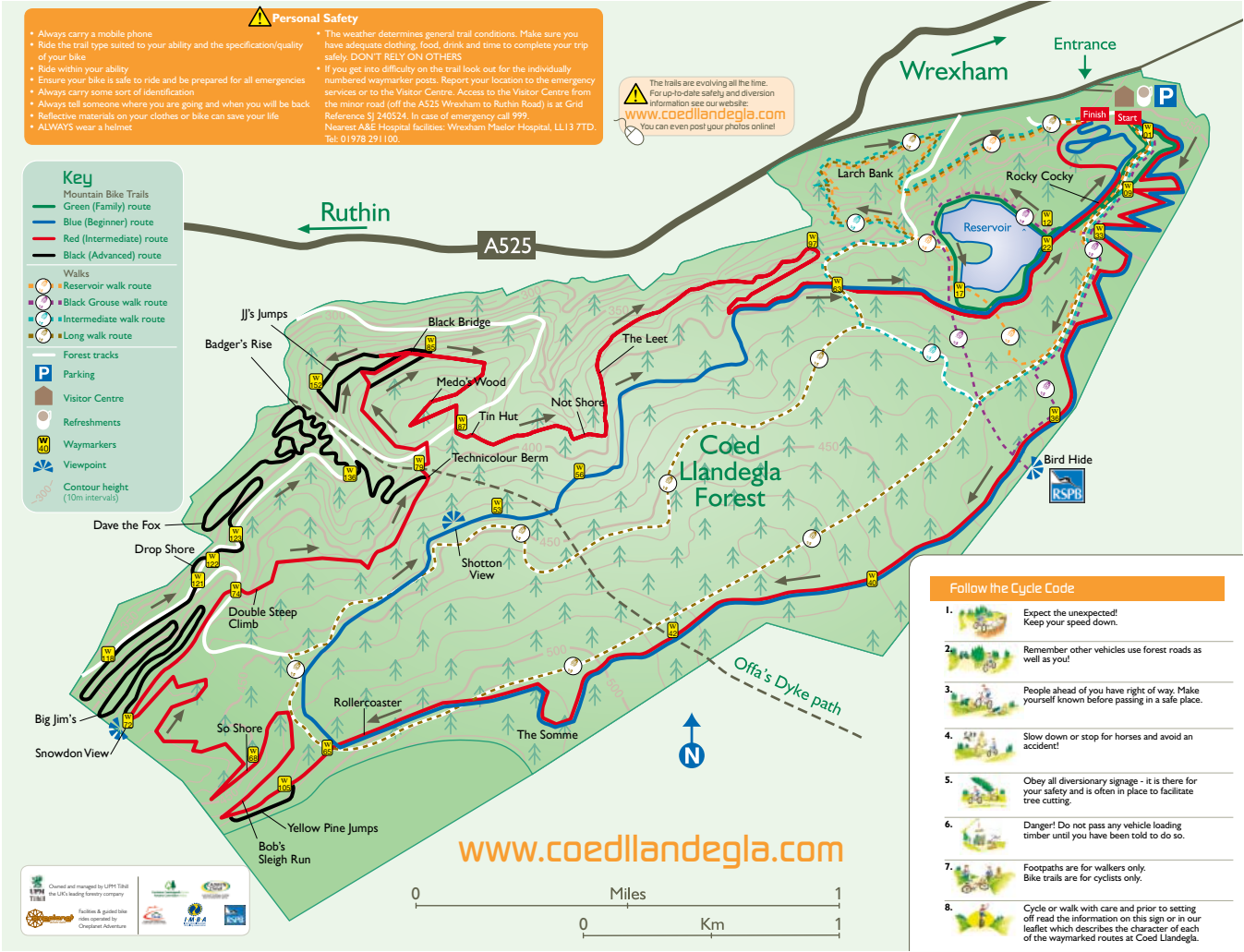
In 2007 the Centre recognised that its current accommodation was inadequate to meet the requirements of its rapidly growing community of cyclists and walkers. UPM Tilhill with the support of the FCW and the Centre's management company OnePlanet proposed a number of additions to the existing accommodation to ensure that the centre could continue to offer safe and enjoyable recreational facilities.

An established relationship between the Project Team, UPM Tilhill and the FCW, encouraged a joint venture to provide an appropriate opportunity to test and develop the findings of the Ty Unnos research project. UPM Tilhill with joint funding from the FCW proposed a design brief for consideration by the Design Research Unit Wales (DRU-w) with Coed Cymru and Cowley Timberwork, based on the application of a high proportion of homegrown timber, to be sourced from the harvested timber of Coed Llandegla.

For full project details please see Appendix B1.

OPPOSITE PAGE

Figure 8.1: The Coed Llandegla Visitor Centre



THIS PAGE

Figure 8.2: Map of Coed Llandegla Forest cycle and pedestrian routes.

Source : Oneplanet Adventure

Figure 8.3: Panorama of the terraced site and existing lodge looking south

OPPOSITE PAGE

Figure 8.4: The log on log visitor centre.

Figure 8.5: The return cycle route to the visitor centre.

Figure 8.6: Approaching the lodge.

Figure 8.7: The thriving cafe.

Figure 8.8: Panorama of the proposed site looking north.



8.02.1 DESIGN BRIEF

The original design brief produced by UPM Tilhill and OnePlanet proposed the following revised and additional accommodation;

- A classroom to accommodate 25 people, to be accessible independently from the main facility,
- Office accommodation for 8 members of staff, with an additional independent office for 2 persons,
- Showers, changing facilities and lockers for a minimum of 8 people to be robust and durable for public use,
- A covered store for bicycle hire to be operated from the existing cycle shop, to hold a minimum of 25 bicycles,
- To retain the existing café space and provide additional external dining areas,
- Increase the storage accommodation and workshop area currently attached to the existing cycle shop,
- Provide additional kitchen facilities, specifically food preparation and storage areas to supplement the existing kitchen,
- Additional fixed storage for public bicycles.
- Generally the accommodation must provide a high level of security whilst in use and when closed due to the centre's remoteness. All of the proposed accommodation must be appropriate and robust for heavy use with an efficient maintenance program.

8.02.2 OBJECTIVES

The visitor centre at Llandegla was designed in parallel with the proposals for the Ebbw Vale Resource Classroom. Both projects provided an opportunity for the Project Team to acquaint themselves with the design parameters associated with the application of the Ty Unnos components. Initially both projects were approached with similar objectives however due to funding issues the objectives of the Llandegla Visitor Centre were unfortunately not fully realised. The revised objectives therefore focus on the design, detailed design and preliminary costings of the proposal.

COMPONENT DESIGN + CERTIFICATION

- Structural design_ fully calculate and test the structural performance of a box section portalised single storey frame with threaded rod connections, with particular focus on the design options for substructure on a heavily sloping site.

BUILDING DESIGN

- Form and Scale_ to consider the appropriateness of form, scale and materials in a rich and sensitive rural context.
- Finishes_ low-cost, durable and robust finishes will be integrated into the proposed prefabricated system of homegrown timber components internally and externally, and will act as a showcase for the products of the Welsh forest and UPM Tilhill.

DETAILED DESIGN

- Detailed Design_ to consider and apply the detailed design of insulated prefabricated infill panels in conjunction with previously analysed dimensional organisations to coordinate doors, windows, infill panels and cladding options.
- Authority approvals_ to test the response and requirements of Planning and Building Control on the detailed design of homegrown timber components.

MANUFACTURE

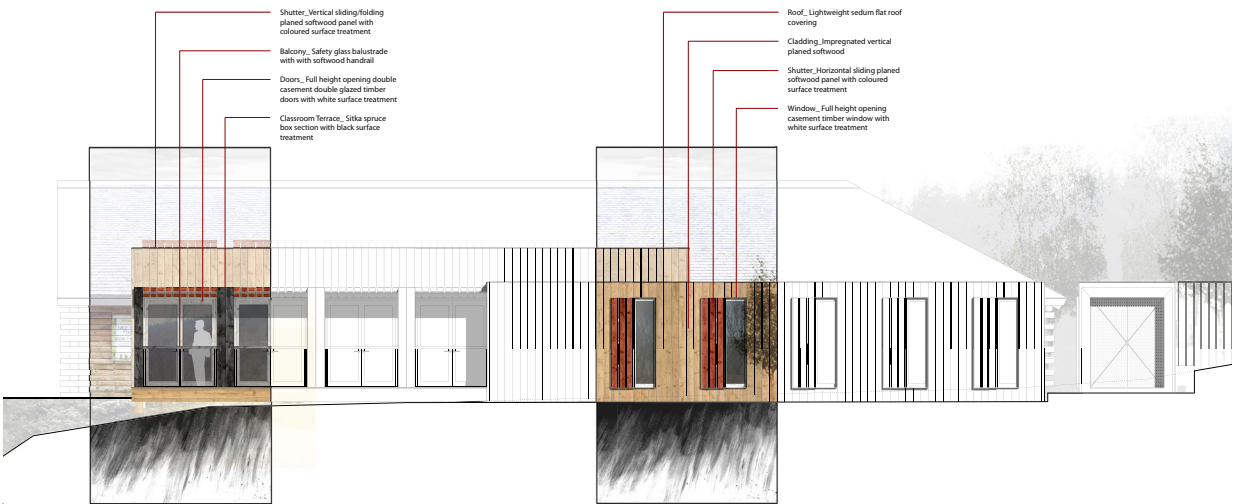
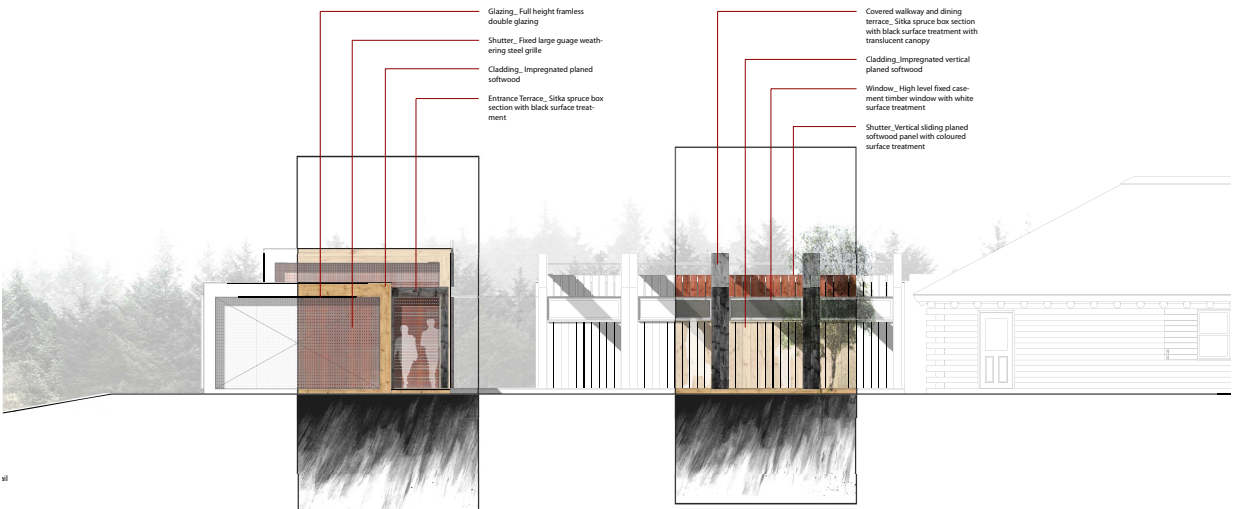
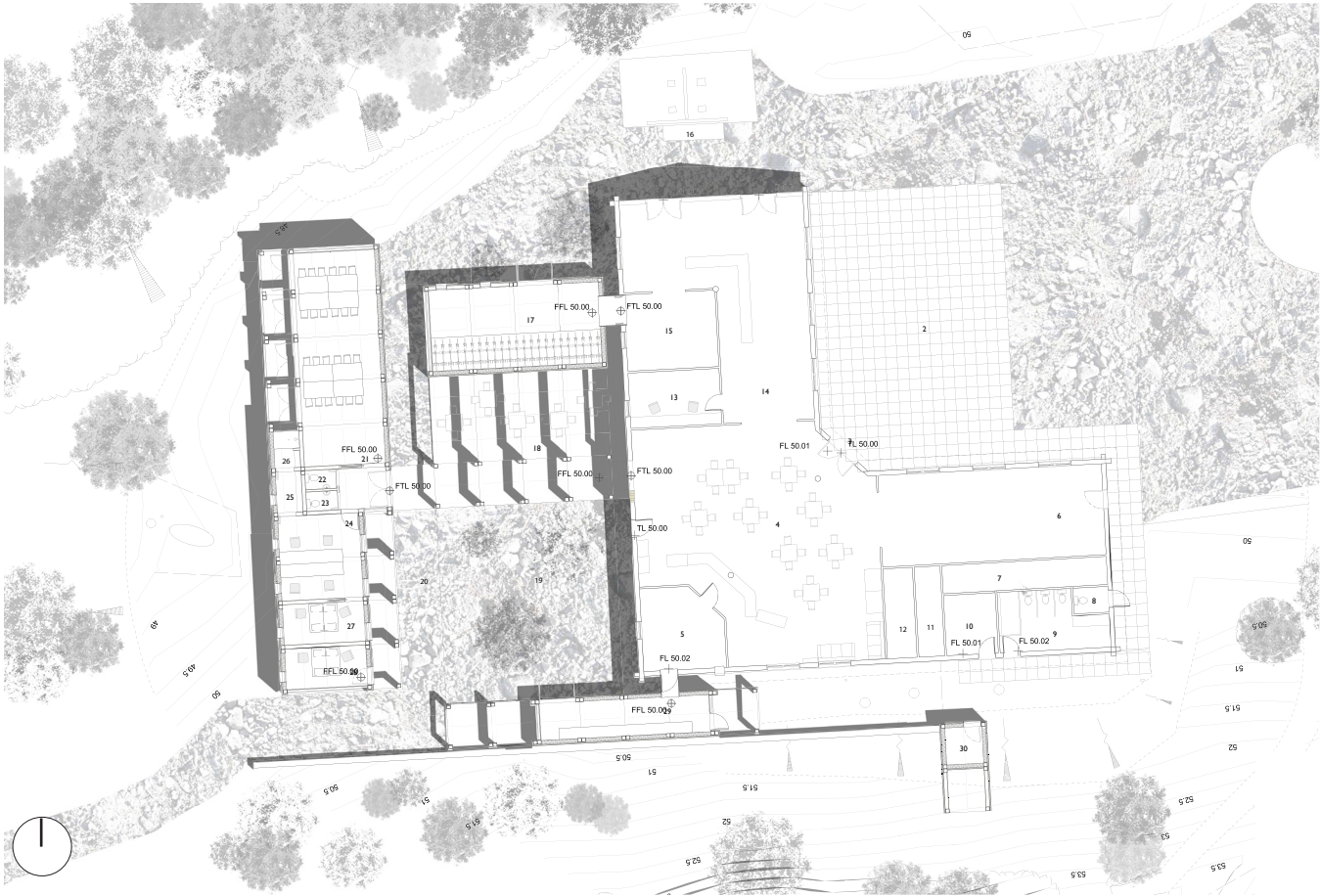
- Material Sourcing_ in order to meet the FC requirements for homegrown timber content, the proposals will examine existing supply chains in Welsh in order to source materials, skills and construction components locally.

CONSTRUCTION / BUILDABILITY

- On site Assembly_ a challenging site with continued public access and limited access for plant and deliveries will provide an opportunity to examine the opportunities and limitations of the proposed components and assembly methods for the primarily prefabricated construction system.

REFLECTION

- Economic evaluation_ to assess the affordability of the proposed system of components within the constraints of a limited budget.



8.02.3 DESIGN

The proposal is designed to form a gateway welcoming the returning cyclist back to the Visitor Centre. It is broken into 3 elements defined by function, dominated to the west of the terraced site by an independent linear volume containing a classroom and office facilities for the centre's staff. The elemental plan and single storey, slender massing reduces the visual impact of the building on its site, sitting sensitively on proposed pile foundations against the low mass of the existing log cabin. Each volume of accommodation is acknowledged in section with floor to ceiling heights modified to suit usage.

External spaces are employed deliberately to provide and deny connections with the landscape. Sheltered terraces offer protected dining spaces for use in all weather and a landscaped dining courtyard allows for less formal use, orientated to maximise the capture of sun. An open veranda provides a protected external pedestrian access to offices and the classroom, distinctly identified against the cycle routes, and a balcony extends the narrow classroom space enabling extensive views to the west.

Externally, materials reflect the natural and agricultural context of the site employing wide vertical planks of homegrown timber, simply treated to allow the natural course of weathering. In contrast to the rustic and robust solid logs of the existing cabin, boards are finished to a planed square edge, detailed with precision to meet openings and edges, and formed into coordinated security shuttering. The roofscape, viewable from the cycle routes above, against the rich landscape of the valley below, employs a flat sedum roof to encourage the naturalisation of this significant elevation. Internally structurally insulated panels employ the palette of available UPM Tilhill board products to provide robust finishes appropriate to the functional application, with Birch plywood to offices and classrooms and melamine coated waterproof boards to food preparation areas.

PREVIOUS PAGE

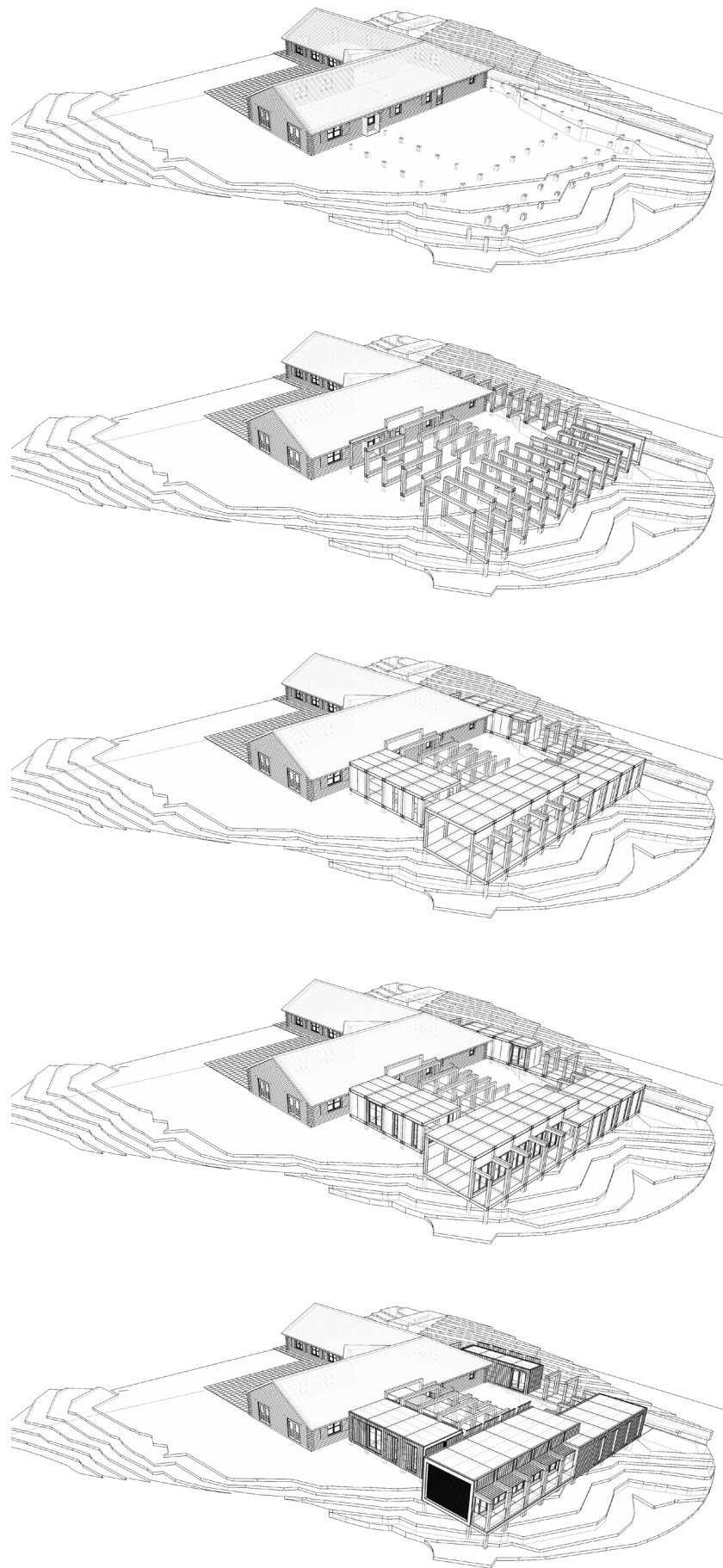
Figure 8.9: Ground Floor Plan.
Not to scale.

Figure 8.10: South Elevation, taken
through dining courtyard.

Figure 8.11: West Elevation.

ABOVE

Figure 8.12: South west view of the
proposals from the returning
cyclist.



- a) Substructure of pad or trench foundations prepared on site, with retaining groundworks to provide a minimum 150mm ventilation zone below suspended timber floor.
- b) Prefabricated box section portal frames assembled and installed at 2.4m centres across the site.
- c) Structurally insulated panels dropped between primary structure and connected to adjacent panels to form floors, walls and roof including providing internal finishes.
- d) Doors and windows manufactured from homegrown hardwood or treated softwood installed into openings
- e) Frameless glazing and Grillage security panels fitted into portal openings to complete thermal envelope. Membranes and external finishes including sedum roof, timber security shutters and external decking installed.

Figure 8.13: Proposed Assembly Sequence

8.02.4 OBSERVATIONS

8.02.4.1 COMPONENT DESIGN AND CERTIFICATION

STRUCTURAL ORGANISATION

- Structural design was performed by Cowley Timberwork in parallel with testing of the box section frame as described in Chapter 6.0.
- Although initially proposed as pad foundations located under the nodes of the primary structural frame, it was resolved that due to the large depth of built up ground, a standard trench foundation to the perimeter of the construction would be most appropriate. This was somewhat disappointing as a key potential of the system is the ability to make use of lightweight footings specifically on sloping sites.
- The use of a 270mm deep box section was proposed for both columns and beams to provide clear spans of up to 4.8m. As the internal face of infill panels provide internal finishes, this results in box beams protruding beyond the face of the infill panels, becoming a visible internal element of the construction. Aesthetically, this was deemed highly appropriate. In order to ensure a fire resistance of 30 mins in compliance with Building Regulations Part K, a 30 min fire resistant coating was specified.

8.02.4.2 BUILDING DESIGN

FORM AND SCALE

- It is difficult to conclude the success of this objective as the extensions were never completed, however I believe that the proposed form and scale was appropriate to its rural context. The project was significantly challenged by the form and scale of the existing log cabin and by an extremely challenging site topography which is perhaps too small to support the accommodation requirements.
- The system has not resulted in any uncomfortable material choices and is capable of supporting the material choices that have been intended by design. Most notably it has been confirmed that the system can be used in conjunction with a sedum roof however, as the system is designed as a perfectly flat roof surface, an additional deck of firing insulation is required to provide the minimal falls required by flat roof materials.
- The dimensional organisation and structural capability of the system has significantly defined the form of the proposal. In general, floor to ceiling heights have been limited to a maximum of 2400mm due to the maximum dimension of standard sheet material. In order to increase this height to the classroom area, a clerestory of windows extends the wall height to 3000mm. Although available as an option in this arrangement, it is unlikely

to be an appropriate general solution. The application of a maximum 2.4m span between portals and 4.8m portal span has also resulted in a number of spaces that are proportionally compromised, most notably the long thin classroom, narrow offices and disabled toilets. Where possible, spaces are kept as open plan, reducing the negative effect of these occurrences, and external terraces have been employed to extend the internal spaces into the landscape. Most challenging however are the proportions of the classroom which is likely to be restricted in its flexibility and adaptability to various uses due to its proportions.

FINISHES

- The most notable finding of the detailed design of finishes is the desired application of an underfloor heating system. In order to incorporate this into the design in conjunction with a suspended timber floor it was found to be necessary to provide an additional floating floor on top of the prefabricated infill panel system. The integration of underfloor heating into the infill panel system was not an option. A battened out floating floor of plywood finishes therefore accommodates the heating system within a network of spreader plates, and additionally provides a limited zone for the distribution of other services.

8.02.4.3 DETAILED DESIGN

DIMENSIONAL COORDINATION

- The proposals employ a 600mm centre line grid throughout in plan, section and elevation. This results in a limited number of manufactured components as there is a great deal of repetition throughout the scheme. In order to enable the use of readily available 2.44 x 1.22m plywood panels, the primary structure is set out on a centre line grid at 2.4m centres throughout and generally has a floor to ceiling height of 2.4m. In order to provide the increased height of 3.0m to the classroom a clerestorey of 600mm deep windows complete the structural opening. These walls can not be employed to provide racking resistance.
- As floor and roof infill panels are set out to the centre line of the portal frame each edge panel has to be notched to sit around the post. This is repeated throughout the proposal, therefore there remains a high degree of repetition. However if infill panels were set out to the internal face of the primary structure this scenario could be avoided.
- The 600mm grid is employed in elevation for the setting out of windows and doors. However as a centre line grid is employed in plan the structural opening between columns is 2190mm. Just four types of opening are used in the design;

- 600mm deep horizontal ‘clerestorey’ window
 - 600mm wide vertical floor to ceiling window
 - 1095mm wide glazed door
 - 2190mm wide double glazed door
- This limited number of opening types gives a consistency in elevation however there are concerns that the glazed area available from a 600mm wide opening is too narrow once an appropriate frame dimension is detailed, and a 1095mm wide door is unusually and disproportionately wide.

AUTHORITY APPROVALS

- The proposals met very little resistance during the planning process. In general, public response was extremely positive. Concerns were raised regarding the level of construction traffic and disruption that the project would cause to the surrounding roads. This was considered by most however to be suitably reconciled through the use of a prefabricated system as construction traffic will be programmed into a limited number of deliveries and waste will be minimal.
- Due to the termination of the project it was not possible to complete the Building Control process however preliminary discussions suggested that there were minimal concerns with the proposals. Careful consideration was given to the design of the connection detail at ground level to ensure that the primary structure was suitably protected from moisture. Although proposals were considered, this detail was not suitably resolved.

8.02.4.4 MANUFACTURE

MATERIAL SOURCING

- The design brief detailed the critical importance of incorporating a high percentage of homegrown timber in order to meet the funding requirements specified by the FCW. The project was detailed at a point in the development of the system when a ladder beam based infill panel, although conceived, was not yet available for application therefore SIPS panels were incorporated into the design. This was unfortunate and significantly limited the quantity of locally sourced materials used.
- The proposal incorporated homegrown timber from the immediate locality throughout the primary structure, external finishes and windows. The majority of internal finishes were to be sourced from UPM Tilhill products and therefore typically imported from Scandinavia.
- The detailed design of cladding was significantly complicated by the requirement to incorporate a high percentage of homegrown softwood.

		Kitchen	Workshop	Classroom	Offices	Total
	Gross Area inc External Terraces (GA)	45.3	130.7	86.8	75.2	338
	Gross Internal Floor Area (GIFA)	17.5	41	62	47.8	168.3
1	Superstructure Enclosed_ Sitka spruce (Ty Unnos) 210mm x 270mm portal frames at 2.4m centres, including ground beam Exposed_ Sitka spruce (Ty Unnos) 210mm x 270mm portal frames at 2.4m centres, including ground beam, with impregnation (Tanalith 'E' or similar) and Black coating. Deck panels have ex 25 x 100 grooved Welsh Oak boarding.	4545	7425	13770	7425	33165
		5133	19605	5670	5670	36078
2	External Walls <i>No of Panels</i> A) The reference 'basic' 2.4 x 1.2m SIP has 15mm grade III coniferous plywood on both faces of 140mm Platinum EPS. 'U' value 0.20. Design, supply & deliver. B) Increase in thickness to 225mm o/a ('U' = 0.14) C) Increase exposed face to grade II with extra selection D) Intumescent Class 'O' flamespread control + sealer E) Impregnation (Dricon) instead. As 'D' plus F) Resistrix EPDM membrane 1000 wide pre-fixed to roof panels G) Lighter grade Resistrix to wall panels. (330 wide joint strip by others)	30 5670 990 888 1470 9018	52 9828 1716 156 1924 728 1776 2100 18228	104 19656 3432 312 3848 1456 3108 5040 36852	60 11340 1980 180 2220 840 1776 2940 21276	246 46494 8118 648 7992 3024 7548 11550 85374
	Totals Total_ inc Option A Total_ inc Options A-B_ U-value 0.14 Total_ inc Options A-D_ U-value 0.14 Total_ inc Options A-G					115737 123855 132495 154617
	Total Price per GIFA Square m inc Options A-B Total Price per GA Square m inc Options A-B	640.2857 360.6623	462.658537 295.133894	594.483871 489.9539171	433.996 351.263	521.551 366.435

Table 8.2: Comparative summary of quotations prepared by Cowley Timberwork, 1st September 2008.

This required considerable research to develop an appropriate treatment specification and programme to ensure a suitable life expectancy. Due to the termination of the project this was not fully resolved however the general conclusion was that a Tanalith E impregnated treatment, available in either brown or green, was required to ensure that softwood could achieve an appropriate durability. If specified as a surface applied treatment, an opaque system would be required with an associated 5 year treatment programme, to ensure durability. These findings were disappointing generally as the result would be in conflict with the design intention, which hoped to demonstrate the natural colour and texture of the timber and allow a gradual weathering of the cladding.

8.01.5.5 CONSTRUCTION / BUILDABILITY

- Due to the project being placed on hold, it was not possible to fully resolve objectives related to on site construction, however throughout detailed design the assembly process remained under careful consideration. It was proposed that portal frames could be manufactured and assembled off site by Cowley Timberwork and transported as complete units to be lifted into place on site. Due to the limited site access and work area it was determined however that as the majority of individual components were of a scale and weight appropriate for assembly by hand or small machinery, the assembly process would be much more flexible and less disruptive to the centre if the prefabricated components were delivered as individual elements and assembled on site.

8.02.4.6 REFLECTION

ECONOMIC EVALUATION

- Table 8.1 shows a comparative summary of the Cowley Timberwork quotation issued on 1st September 2008. The quotation details a number of options for prefabrication including alternative specifications for internal plywood finishes, treatments and the pre fixing of EPDM membrane.
- The cost assessment is complicated by the large areas of external terracing included in the costs. An approximation therefore suggests that the cost per m² of internal floor area without the inclusion of external terracing is £521 per m². With the inclusion of external terracing this reduces to £366 per m².
- Dependent on the specification, this quotation includes as standard the supply of an insulated structural envelope to give a U value of approximately 0.15 W/m2, including the majority of internal finishes, with the exterior prepared to receive external claddings.

8.03 ENVIRONMENTAL RESOURCE CENTRE
THE WORKS, EBBW VALE

PROJECT SUMMARY

Architect Design Research Unit Wales
Client Blaenau Gwent County Council
Main Contractor G Adams Construction
Manufacturer Cowley Timberwork
Completed May 2010
Value £330 000
Contributions include
concept and site studies, planning
application support, presentation
images and modelling, detailed design,
client and design team communication,
and monitoring of on site construction.



The Environmental Resource Centre (ERC) at The Works in Ebbw Vale has been designed by the Design Research Unit Wales (DRU-w) for Blaenau Gwent County Borough Council and is the first commercially completed project to use the Ty Unnos Sitka Spruce construction components. The sustainable building combines low cost Welsh timber, high levels of insulation and a state of the art heating and ventilation system to provide an environmentally friendly and innovative building.

The 140 square metre ERC is also the first building to be completed on the site of the former Steelworks as part of The Works regeneration project. The £300 million project includes 720 new homes, a community hospital, learning campus, business hub and improved national connections including a dedicated rail terminus.

Located on an ecologically rich site next to the former Pumphouse cooling ponds, the centre provides educational facilities to allow local school children and the community to explore the heritage and ecology of the former steelworks site.

For full project details please see Appendix B2.

8.03.1 DESIGN BRIEF

The functional brief produced on behalf of Blaenau Gwent identified the following aims and objectives;

- To design and build an environmental resource centre as a high quality destination to inspire learning, appreciation and enjoyment of the natural landscape and the environmental and biodiversity habitats on the site of the former steel works pump house and filtration tanks;
- To be delivered by the end of March 2009 for approximately £150,000;
- Accessible, welcoming, inclusive, user friendly and safe centre of learning, leisure and tourism for all age groups that incorporates measures to

OPPOSITE PAGE

Figure 8.14: The Pumphouse and cooling ponds, now considered an area of environmental interest.



OPPOSITE PAGE

- Figure 8.15: The red brick Victorian pumphouse, proposed for renovation and reuse.
- Figure 8.16: The original concrete cooling ponds remain filled with water, now providing a habitat for a wide variety of wildlife.
- Figure 8.17: A network of timber boardwalks provides access across the cooling ponds.
- Figure 8.18: The cooling ponds have provided a habitat for dense reeds.
- Figure 8.19: To the South of the pumphouse, a flat area of virgin ground is to be relandscaped with further gardens and a car park.

ensure security against vandalism, fire damage and theft;

- Physically attractive development that has a strong sense of identity making the most of the existing Pumphouse and settlement tanks;
- A sustainable development that is resource efficient and ecologically rich, maximising the use of passive and renewable design measures for heating and ventilation, and considers the use of rainwater harvesting, grey water recycling and on site waste treatment and management;
- The building will act as an exemplar development with regard to protecting and enhancing local biodiversity, and minimising site disturbance during and after construction;
- Facilities will include a classroom to accommodate 30 children with generous storage space for furniture and equipment, an office with basic kitchenette, toilet facilities including a unisex disabled toilet, and a covered collection area for groups;
- The interpretation and display facilities of the Resource Centre will be supported by various natural and landscaped areas around the pumphouse site coordinated by Halcrow.
- To use the Ty Unnos construction system developed by Coed Cymru, Design Research Unit Wales and Bangor University with Cowley Timberwork;

8.03.2 OBJECTIVES

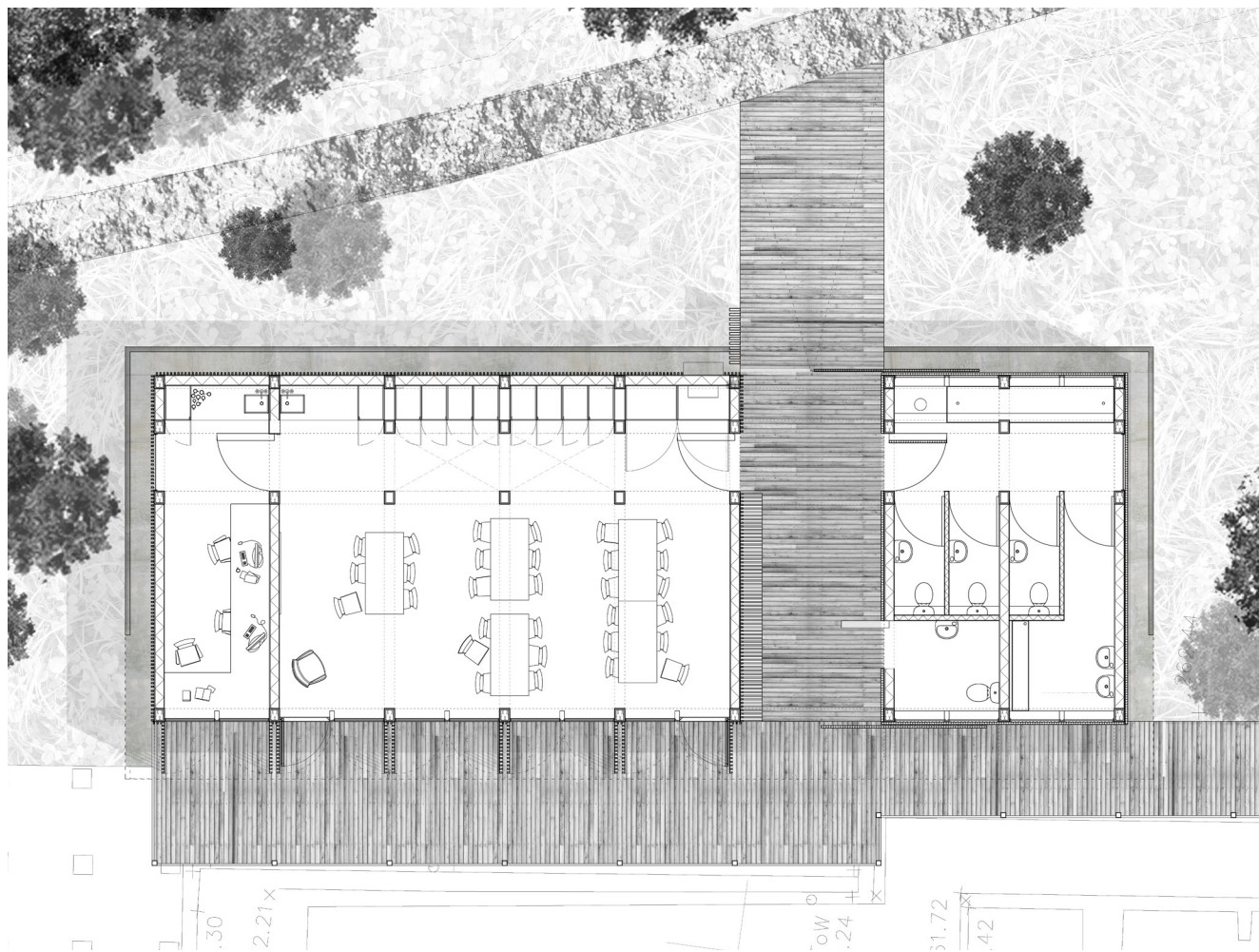
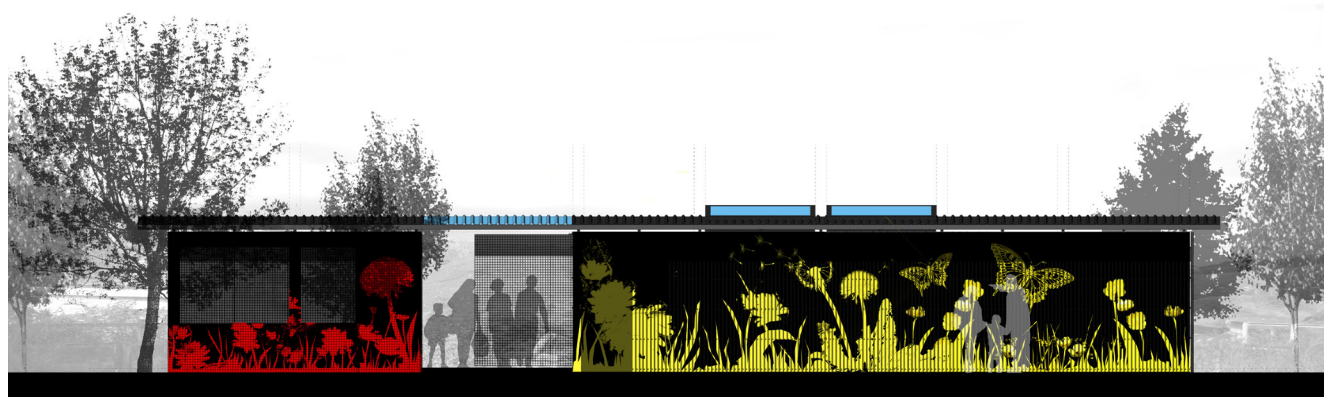
The Environmental Resource Classroom provided the first opportunity to test componentry, in this case a portalised box section frame with infill SIPS panel, and focused primarily of the manufacture and construction of homegrown timber components.

COMPONENT DESIGN + CERTIFICATION

- Structural Organisation_ fully calculate and test the structural performance of a box section portalised single storey frame with threaded rod connections.

BUILDING DESIGN

- Scale_ the project is the first realised application of paper based studies into the scale, and dimensional coordination of the proposed construction components. Building design will test the limitations of component spans and imposed design rules and the realised construction will provide the first spatial reflection of these studies.
- Finishes_ low-cost, durable and robust finishes will require integration into the manufacture of system components in order to provide exposed finishes internally.



DETAILED DESIGN

- Detailed Design_ to consider and apply the detailed design of insulated prefabricated infill panels to be assembled by hand on site in conjunction with a load bearing structure
- Services_ To consider the integrated design of services with a prefabricated and exposed thermal envelope and primary structure.
- Authority approvals_ The fulfilment of Planning and Building Control obligations will look to identify limitations or concerns associated with the detailed design of construction components.
- Environmental performance_ in order to meet the requirement of a 60% reduction in Building Regulations, the system will be tested against high requirements for thermal performance.

MANUFACTURE

- The active full scale manufacture of homegrown timber components will test the supply chain and manufacturing processes in a highly skilled manufacturing environment.

CONSTRUCTION/BUILDABILITY

- A constrained programme and restricted site will test the buildability of the proposed system of components and evaluate the advantages and disadvantages provided by the off-site manufacture of components.

REFLECTION

- Economic evaluation_ to assess the affordability of the realised system within the constraints of a limited, publicly funded budget.
- Occupational response_ the occupation of the building will provide an opportunity to assess the spatial quality of the realised building and applied system of components.

PREVIOUS PAGE

Figure 8.20: East elevation showing applied supergraphics of local wildlife.

Figure 8.21: Ground floor plan.

Figure 8.22: West elevation with shutters which open to the boardwalk and cooling ponds beyond.

THIS PAGE

Figure 8.23: The Centre and network of boardwalks placed immediately adjacent to the cooling ponds of the former steelworks.



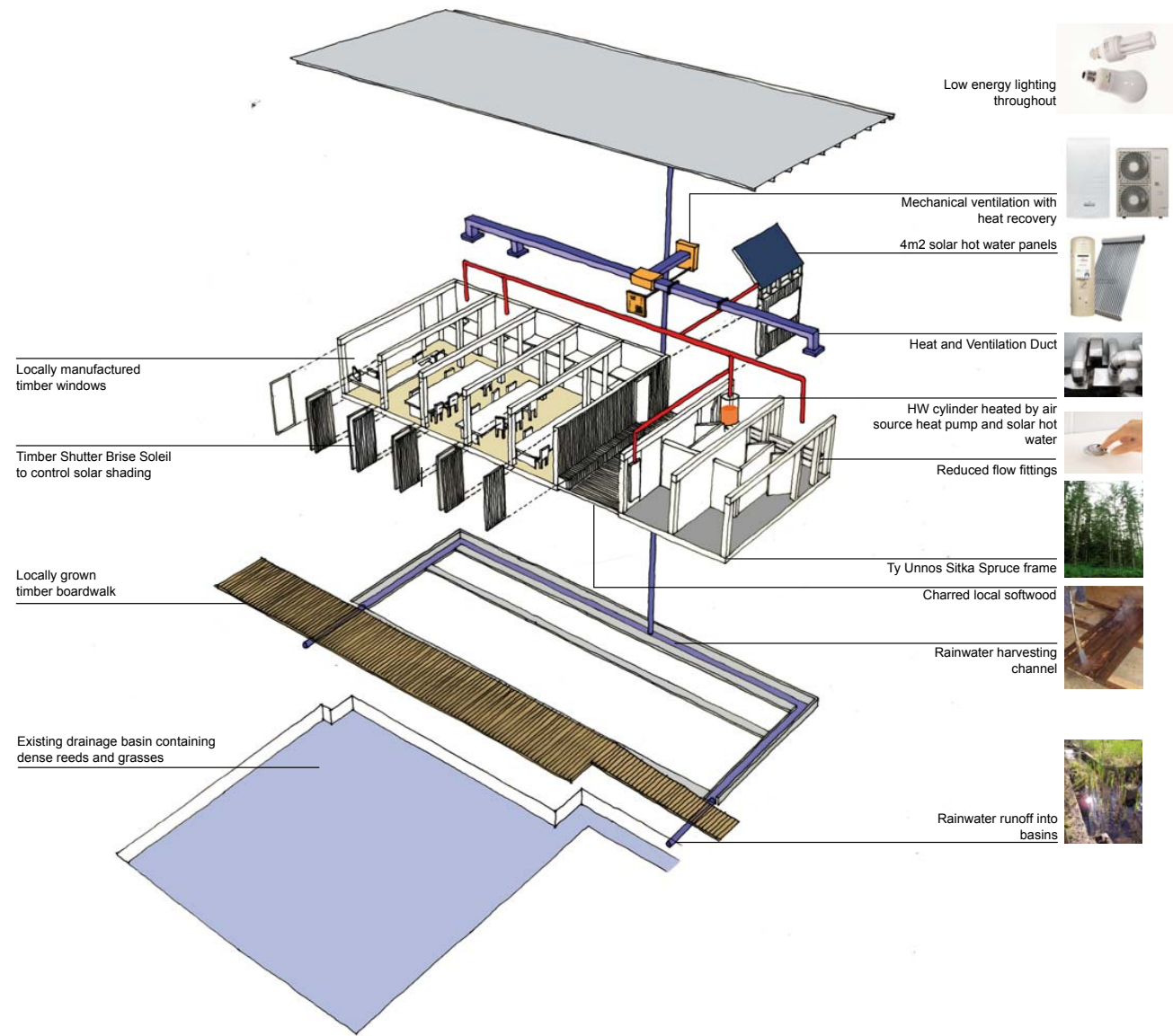
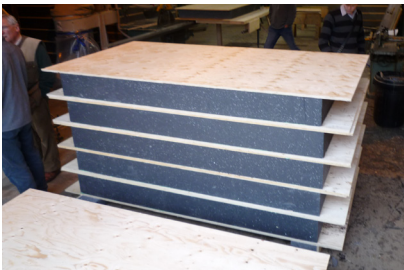


Figure 8.24: Proposed environmental and sustainability strategy to achieve a 60% reduction over Building Regulations Part L.

OPPOSITE PAGE

- Figure 8.25: SIPs panels being pressed, 3 at a time.
- Figure 8.26: Once laminated, the insulation lamination is machined to receive junction profiles.
- Figure 8.27: Preparing male and female hidden connection.
- Figure 8.28: Male connector glued into place within the insulation zone.
- Figure 8.29: Deliveries were stored in the transportation containers until required on site.



8.03.3 DESIGN

The classroom is located in response to the geometry of the former pumphouse cooling ponds. A simple rectilinear form is located alongside the cooling ponds in an area of wild grasses. Two key axes zone the building. An oak deck links the access pathway through the building to the boardwalk. This separates the classroom from the service block and addresses the level change between the path and the boardwalk. A second longitudinal axis separates a service zone along the eastern edge of the building from the main inhabited spaces overlooking the cooling ponds and valley beyond.

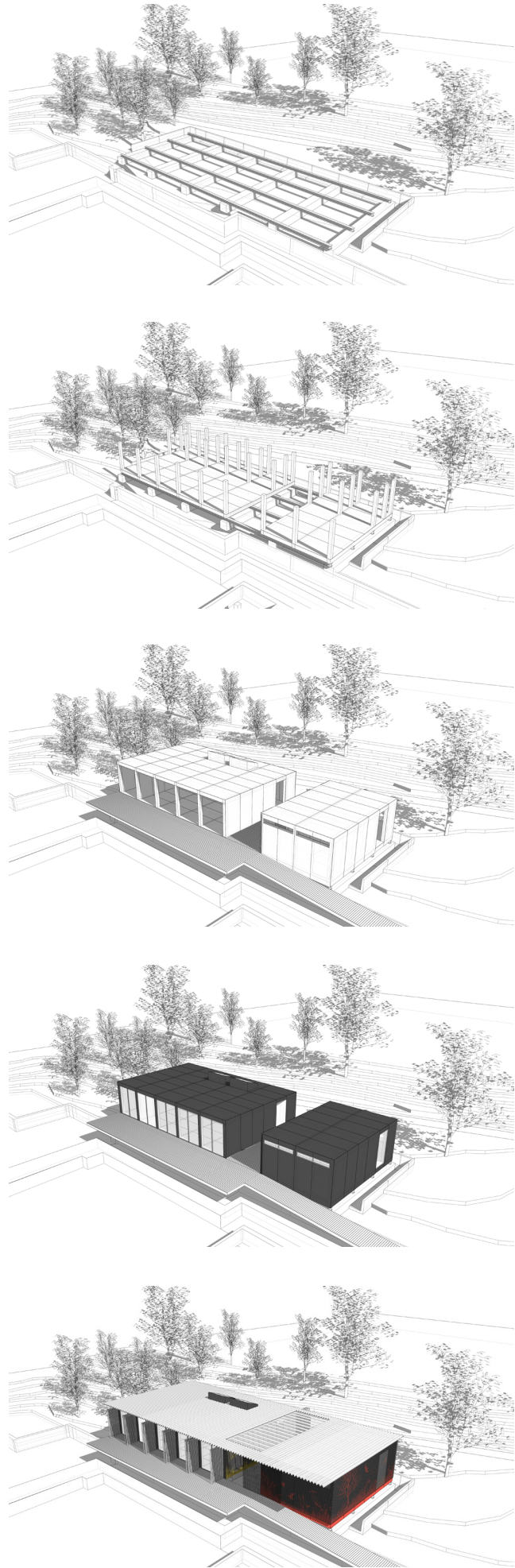
To the north of the entrance axis a large classroom opens to the filtration tanks through folding screens. Internally, the birch plywood layers of structural infill panels provide robust finishes to floor, walls and ceilings. To the East a prefabricated storage wall encloses services, a kitchenette and worktops, whilst providing storage for the room's furniture. A large office opens off the classroom providing a secure working environment for the facility's operators.

To the south of the entrance a service block provides robust, serviceable facilities. Drawing on the industrial context, finishes include galvanised and stainless steel and black marmoleum.

The Centre is designed to achieve a 60% reduction over Building Regulations using locally sourced materials where possible. This is achieved through the design of a building envelope that provides high U-values and air tightness in parallel with an intelligent response to site, embracing solar gains during the winter months and natural daylight. West facing full height openings and large roof lights provide good lighting conditions all year round in the classroom. An oversailing lightweight roof and shutters ensure that solar gains can be controlled during the summer months. The building uses a natural ventilation strategy provided by trickle vents and opening casements in combination with an air-to-air heat exchanger to provide warmed air during the winter and additional ventilation when required during the summer. A solar hot water array provides hot water to the centre.

8.03.4 COMPONENT DESIGN

Cowley Timberwork were appointed as manufacturer for the design and detailing of the Ty Unnos frame and infill panel system for the ERC. The ERC consists of 9 paired portal frames creating 8 bays including an open entrance deck. The portal frames are paired in the east west axis to create a long span of 7.2 metres. Although originally considered as two independent portal frames connected across the main north-south circulation axis, Cowley Timberwork acquired non standard lengths of homegrown spruce to prefabricate 7.2m long 270 x 210mm floor and roof box section beams, see Fig. 8.32. 270 x 210mm Columns lining



- a) Hot rolled steel I section substructure
- b) Structurally Insulated Panels (SIPs) to span between portals as a suspended floor
- c) SIPs infill panels span between roof beams to cerate roof deck. Infil panel upstands create falls for rooflights. A secondary roof deck is installed using furring battens and plywood to ensure suitable falls beneath the lightweight roof
- d) Windows and doors manufactured using small section oak and SIPs Panel entrance doors installed.
- e) Galvanised sinusoidal steel roof installed with profiled steel gutter along the east elevation

Figure 8.30: Proposed construction sequence.



Figure 8.31: Box section lamination press.
Figure 8.32: 7.2m box beams prepared with additional supporting timbers installed to floor beams
Figure 8.33: Threaded rod connection detail with spreader plate and rolled I section foundation connector.
Figure 8.34: Floor beams and columns installed on site.

the north-south circulation routes are then employed as structural props to the extended floor and roof beams. Portal frames are located at 2.4m centres along the north-south axis. 210mm thick Structurally Insulated Panels (SIPs) span between portal frames to provide floor, wall and flat roof infill with a U-Value of 0.15 m²K/W. Standard SIPs have been uprated for the ERC to include Birch plywood or Spruce plywood laminations to the internal faces. This surface is treated with fire retardant and provides all finished internal surfaces. A male/female timber connection is adhered into the insulation zone of each panel along the long edges during manufacture to provide connection with neighbouring panels see Fig. 8.28.

8.03.5 MANUFACTURE AND CONSTRUCTION

Cowley Timberwork originally proposed a 40 day design and fabrication programme. Gordon Cowley of Cowley Timberwork highlighted considerable issues arising from the manufacture of the Ty Unnos frame and SIPs system causing a cost and programme over run of 50%;

- Sourced homegrown Sitka Spruce caused considerable delays due to the machining taking longer than first estimated. Machine wear was extremely high due to the hardness of Sitka Spruce knots causing end cutters to break and wear frequently, resulting in repeated stoppages.
- A key issue with the production of glue laminated beams and box section beams is the accuracy of the machined beam. Cowley timberwork did not have a four face planer and therefore machining of the square section was performed on a thicknesser with a short bed of only 1 - 1.5m. Due to the weight and lengths of the beams, any slight twist along the beams length can easily cause the beam to move during planing to follow the twist rather than enforcing an accurate section.
- Cowleys typically manufacture SIPs to a thickness between 100 and 150mm however the SIPs specified for the ERC were 210mm thick. The additional thickness caused considerable delay as the machinery was not set up to press, cut and profile to this depth, typically requiring two passes through processes.

For further details please see the manufacturer response questionnaire in Appendix B2.

8.03.5.1 SUBSTRUCTURE

The design and construction of the substructure was frustratingly complex. Four concrete trench footings were demanded by ground conditions running east - west on the short axis of the building. A perpendicular substructure of steel was employed to provide connection between the concrete footings and the primary timber frame and maintain a 150mm ventilated void. This substructure enabled



Figure 8.35: Floor infill assembly sequence
FROM TOP LEFT ACROSS - DOWN

- a) lifting panel into place
- b) lowering panel between box section structure
- c) locating panel on timber ledge
- d) sliding panel to make connection with installed floor panels
- e) repeating process,
- f) lifting panel into place
- g) lowering panel between box section structure
- h) locating panel on timber ledge
- i) sliding panel to make connection with installed floor panels

OPPOSITE PAGE

- Figure 8.36: Craning precast concrete retaining wall structure into place.
- Figure 8.37: Steel I section substructure anchor bolted into transverse concrete trench footings.
- Figure 8.38: Threaded rod connectors installed into the bottom end of columns.
- Figure 8.39: Panel installed onto timber ledge, spanning between primary floor beams.



the contractor to prepare elongated holes to receive the threaded rod extensions of the primary structural frame connector, with a relatively high capacity for tolerances. The substructure design incorporated a drainage channel to the perimeter of the building using prefabricated concrete retaining panels. This system ensured that ventilation was maintained beneath the suspended timber floor with a clear space of over 200mm between 'ground' and the lowest structural timber, whilst providing a level access. The significant alteration of levels this demanded was achieved by removing soil immediately beneath the building and increasing levels around its perimeter.

8.03.5.2 PRIMARY STRUCTURE AND THERMAL ENVELOPE

A number of issues were observed during the assembly of the primary structure;

- The accurate setting out of the primary structure was challenging due to the lack of any guides or retaining structure between portal frames. Assembly therefore relied on elongated holes prepared in the steelwork substructure to allow continuous adjustment of the frame positions during the installation of infill panels.
- Columns shifted marginally from a true vertical during the tightening of threaded rod connections. It is believed that this is due to the over tightening of bolts causing localised compression of the end grain timber to the bottom of the column. The knock on effect was slight discrepancies when infill panels and roof beams were installed.
- As columns and roof beams are to be exposed internally, additional protection was required during construction. Although reasonably successful there are a number of areas of damage to the relatively soft and compressible Spruce columns.
- All beams and columns were prefabricated with an infill of sheep's wool insulation with the end section of beams left free of insulation to ensure a clear route for threaded rod connections. Completion of this infill when on site was originally omitted.
- With beams and columns installed and the floor and wall infill panels in place, the installation of the roof beams was a considerable challenge. The installation of panels required the roof beam to be installed as the last step of the assembly process, therefore adjustments to the position of column to ease the location of the threaded connector rods was severely restricted.
- Infill Panels were constructed with a maximum dimension of 1200 x 2400mm. All panels could be manually handled by four people. The panels are dropped into location between box section floor beams and located on a rigid plate fixed to the box section beam. Adjacent panels are



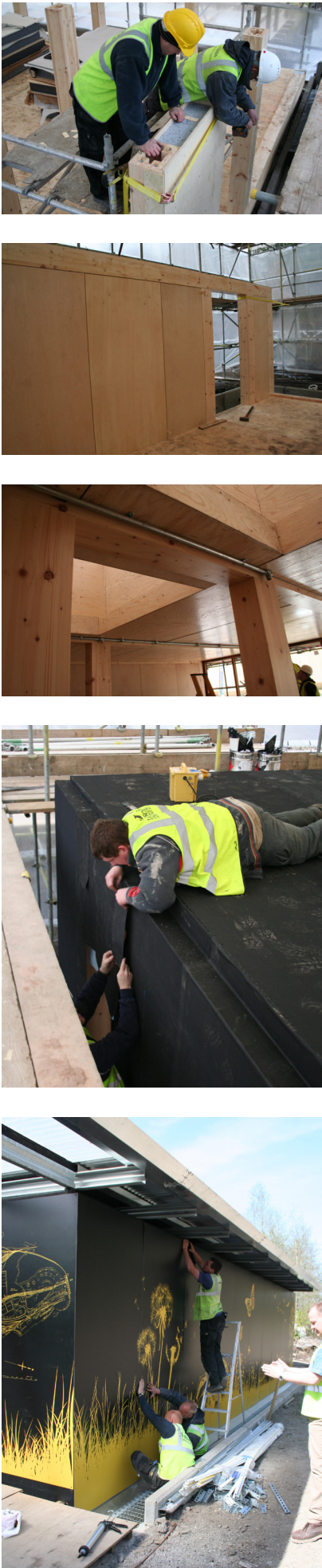
Figure 8.44: Construction sequence of the ERC.

FROM TOP LEFT ACROSS - DOWN

- a) Trench footings cast.
- b) Substructure of steelwork installed on trench footings with precast concrete retaining panels during installation.
- c) Within the scaffolding enclosure, spruce floor beams and columns installed on footings.
- d) Floor panels installed and wall panels in process.
- e) External wall and roof panels partly installed.
- f) Infill panel installation complete including roof light upstands
- g) Sinusoidal steel roof installed over EPDM rubber membrane.
- h) Installation of precut metal cladding with applied coloured wildlife supergraphics.
- i) Overcladding of charred timber hit and miss battens and stainless steel grillage.

OPPOSITE PAGE

- Figure 8.40: Craning precast concrete retaining wall structure into place.
- Figure 8.41: Steel I section substructure anchor bolted into transverse concrete trench footings.
- Figure 8.42: Threaded rod connectors installed into the bottom end of columns.
- Figure 8.43: Panel installed onto timber ledge, spanning between primary floor beams.



located and locked together using a hidden male/ female timber junction shown in Fig. 8.39.

- Onsite assembly of the primary structure, floor panels, wall panels including internal walls, and roof panels took approximately two weeks.

8.03.5.3 SERVICES AND FINISHES

- SIPS panels are designed with an internal lamination of Birch plywood to provide an exposed lining to all wall surfaces and Spruce ply to the ceiling.
- Designed as a flat roof form, the prefabricated structure and envelope are designed and manufactured to a perpendicular arrangement. In order to provide the necessary drainage falls, an additional deck of furring timbers and plywood is formed onsite.
- The exposed nature of the SIPs panel system makes the integration of services into the thermal envelope very challenging to achieve neatly. Services were therefore designed as surface mounted conduit and fixtures which were considered appropriate to the industrial context of the site location. The suspended timber floor however allowed the majority of the large service distribution to be hidden below the floor deck.
- A multi-layered approach was taken to the external finishes to achieve a dynamic elevation. A layer of EPDM membrane is applied on site to wall and roof. Although initially proposed as an off site operation, this was not considered cost effective due to the number of joints that would require completion on site. Layers of lightweight metal panels illustrated with brightly coloured murals of wildlife scenes are then applied. To the service/ WC block galvanised steel grillage is applied providing additional security and robustness. To the classroom block home grown softwood battens are charred and applied as a hit and miss cladding including hinged shutters across openings. The weight of external finishes, particularly the steel grillage, proved to be a concern, requiring additional structural calculation to assess the pull out capacity for fixings installed into the infill panels.

8.03.6 OBSERVATIONS

8.03.6.1 COMPONENT DESIGN + CERTIFICATION

STRUCTURAL ORGANISATION

- The structural organisation of portal frames with threaded rod connectors provided an efficient solution for this scale of application. The connection in conjunction with the required assembly process however resulted in a number of concerns regarding tolerances, as the threaded rod junction allows for very limited dimensional discrepancies. The accuracy of the required junction was made particularly evident by the construction

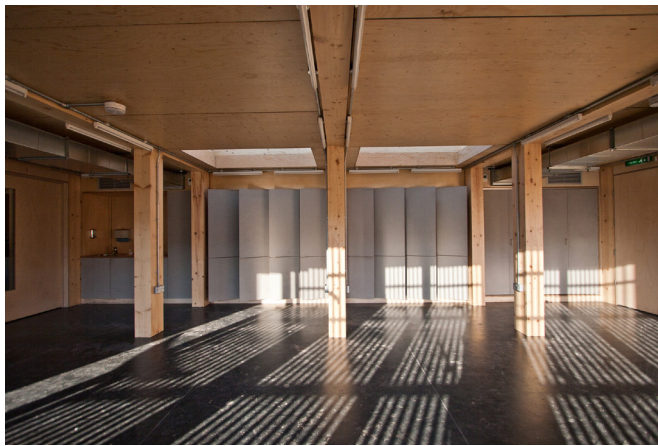


Figure 8.45: View of the west elevation across the cooling ponds.
Figure 8.46: Looking into the classroom with the service and storage wall in the background.
Figure 8.47: Glazed openings look out across the boardwalk and cooling ponds.

OPPOSITE PAGE

Figure 8.48: Ventilation ducts and electrical conduits and fixings installed in the office.
Figure 8.49: and the classroom.
Figure 8.50: Electrical points surface mounted to spruce colonnade.



sequence which required the installation of infill panels prior to the completion of the portalised frame.

- Once assembled the structure including infill panels provided an extremely robust envelope with very little awareness of deflection under use.

8.03.6.2 BUILDING DESIGN

SCALE

- Infill panels are designed to the maximum dimensions of standard plywood board sizes of 1220x2440mm. In order to provide suitable connections, this has resulted in a maximum floor to roof beam height of 2340mm. In a space of this geometry and organisation, this feels somewhat limited.
- The 4.8m clear span of the classroom space is limited for this type of occupation, however the extension of this space with a colonnaded circulation zone and service wall extends the room spatially with great success.

FINISHES

- Internal finishes have drawn on the industrial nature of the site with surface mounted conduits, service ducts and electrical fixtures. Whilst this aesthetic is successfully achieved, the density and scale of the required fixtures is slightly overwhelming in the relatively low classroom space.
- As internal finishes are provided by the primary structure and infill there are areas of finish that are slightly disappointing. Most notable is the consistency of shadow gaps between infill panels and primary structure. This is not considered to be due to the quality of manufacture or workmanship but rather a result of the on site tolerances required when employing off site finished components.

8.03.6.3 DETAILED DESIGN

- The detailed design of the thermal envelope was significantly complicated by the intention to employ the integrated layers of prefabricated components to provide internal finishes. In order to achieve a fixing free coordinated appearance, the geometry and manufacture of infill panels required considerable planning and attention to detail. The result is a large number of alternative panel types and a panel specific assembly sequence.
- From this process it can be concluded that an element of on site finishing, ie the application of dry linings, is likely to significantly improve the efficiency of the design, manufacture and assembly of a system build.



Figure 8.51: View of the south and west elevation with the grillage clad toilet block in the foreground.
Figure 8.52: Lit up by LED lights at night.
Figure 8.53: A small area of solar water panels identifies the primary entrance.

OPPOSITE PAGE

Figure 8.54: The site following groundworks.
Figure 8.55: The scaffolding tent providing protection from the weather.
Figure 8.56: Installing a roof panel from a small scaffolding tower.

AUTHORITY APPROVALS

- There were few unusual issues highlighted by Planning and Building Regulation approvals. The Design Commission for Wales responded very positively to the system's primary objective of employing sustainable locally sourced Sitka Spruce in the construction industry.

ENVIRONMENTAL PERFORMANCE

- The ERC has successfully met the intended target of a 60% reduction over 2006 BR Part L with limited demands placed on the Ty Unnos componentry thanks to the high performance SIPs envelope achieving a U-Value of 0.15 m²K/W. It has been necessary to incorporate seals into the infill panel design to ensure that a high level of airtightness is achieved between panels and the primary structure.

8.03.6.4 MANUFACTURE

- The manufacture of components provided a number of useful observations related to sourcing and manufacturing processes. Of particular note is the experience of machining Sitka spruce in large quantity, which caused considerable wear to machinery, and posed a number of significant challenges resulting in an increase in manufacturing costs and programme of 50%. Cowley Timberwork are confident however that many of these issues can be resolved for future applications.



8.03.6.5 CONSTRUCTION/BUILDABILITY

- The advantages of off site manufacture has been relatively unsuccessful in delivering a sensitive construction solution on the ecologically rich site due to the necessity for mass concrete footings. The need to combine a Part M compliant access with existing site levels and suitably ventilate below the primary structure posed a considerable design challenge and resulted in substantial earth movements around the building site.
- Once above ground however, the erection of the frame and thermal envelop was achieved in less than the programmed 15 days, with minimal complication and generally without requirement for substantial mechanical assistance. Panels with a maximum size of 1200 x 2400mm could be handled by a minimum of 3 people.
- In order to protect the exposed finishes of the thermal envelope from very challenging weather conditions, a canopy of scaffolding was erected over the building site, remaining in place for nearly four months. This was a radical, but entirely necessary approach as the construction sequence resulted in the intended internal finishes being installed early in the construction process and remaining exposed to the weather for a



Figure 8.57: East and entrance elevation with the Works development site in the background

Figure 8.58: Timber and grillage shutters providing security and solar shading.

Figure 8.59: Large rooflights provide relief at the rear of the classroom.

Figure 8.60: Birch plywood SIPs doors to the toilet cubicles.

significant period of time.

- The primary contractor has responded very favourably to the system and would be happy to work with the system in a similar fashion again. Although guidance was required from Cowley Timberwork and DRUw to ensure the construction sequence was accurately followed, there was little need for additional training on site with most tasks easily accommodated by the on site construction team.

8.03.6.6 REFLECTION

ECONOMIC EVALUATION

- The ERC has provided a comprehensive evaluation of the economics of the Ty Unnos construction components. The contract value at tender stage was agreed at £315,000, approximately £2250 per m². However this figure is inflated by a number of items including expensive ground works due to site context, high levels of glazing, and a significant Mechanical and Electrical budget. Throughout the project, a number of cost studies were performed and measures suggested to reduce costs, however the client and user were keen to deliver the highest quality building possible and therefore endeavoured to find additional funding.
- The realised cost of the Ty Unnos frame with SIPs based infill panels and doors including internal finishes came to an approximate total of £64,000 supplied by Cowley Timberwork. Erection of the Ty Unnos frame and infill panels to provide thermal envelope was approximately £4000. This equates to approximately £485 per m².

OCCUPATIONAL RESPONSE

- The completed building has received a very positive response. Initial concerns of the client and user group suggested the building might feel lightweight or temporary, however the reality is a high quality building with a robust envelope providing good acoustic and thermal performance which sits routed in its site with a definite permanence.

8.04 THE WELSH FOLKLIFE FESTIVAL PAVILION
THE SMITHSONIAN INSTITUTION, WASHINGTON DC

Project Summary
Architect Design Research Unit Wales
Client Coed Cymru
Main Contractor Kenton Jones Joinery
Manufacturer Cowley Timberwork
Completed June 2009
Value £40 000
Contributions include
detailed design, client and design
team communication, and monitoring
of manufacturing and pre-assembly



Each year a nation, region, state or theme is invited to be the subject of an international open air festival situated on the National Mall, Washington, DC. Hosted by the Smithsonian Institute, the festival is an exposition of living cultural heritage lasting for two weeks every summer over the 4th of July national holiday and drawing more than one million visitors. In late 2008, the Welsh Assembly Government announced the launch of the Welsh Folklife Festival to be hosted in the summer of 2009. Following considerable public interest in the Ty Unnos research project, the Project Team were invited to submit a proposal for the event.

The project team proposed an exhibit entitled *‘learning from the vernacular’* based on the humble vernacular of Welsh rural domestic architecture. The prefabricated exhibit would re-in visage the traditional folk culture of Welsh domesticity to generate a contemporary design model encompassing the sustainable concepts of using local resources, recycled materials and low energy design. The realised pavilion, although considerably scaled back from initial proposals, provided a critical progression in the development and testing of a self build type construction system.

8.04.1 LEARNING OBJECTIVES

The Pavilion occurred midway through the development of the ERC project, however due to the nature and scale of the project, the project offered the opportunity to explore the utilisation of homegrown timber components in a much more comprehensive manner. The Pavilion coincided with a number of trial assemblies using a dimensionally coordinated infill panel based on a homegrown timber ladder beam, taking the place of the previously utilised SIPs infill panels, to span between the box section frame. The Pavilion project therefore provided a well timed opportunity to apply these trials in the design and construction of a large scale prototype, applying engineered homegrown timber components for

OPPOSITE PAGE
Figure 8.61: Constructing the pavilion on the
National Mall, Washington.

The following learning objectives were proposed, coinciding with deliverables and milestones of the Technology Strategy Board project:

- **Structural Organisation_** The structure will employ a pitched portal box section frame arranged at equal centres with infill panels spanning between. The organisation will test the appropriateness of paper based studies into the setting out and arrangement of the primary and secondary structural components, and test alternative junction types for ease and accuracy of construction.
- **Structural Firmness_** in addition to providing an opportunity to develop structural performance calculations, the pavilion will provide an opportunity to assess the perceived firmness of components under live loads such as high footfall and high wind loads.

- Finishes_ throughout the project, homegrown resources or Welsh manufactured products will be employed where ever possible to provide structural elements, internal and external finishes and furnishings.

- **Detailed Design_** the project will develop the detailed design of homegrown timber components in the form of prefabricated infill panels based on engineered Sitka spruce ladder beams. Specifically this will look at the primary connections made between panels and frame.
- **Dimensional Coordination_** the project will employ a 600mm dimensional grid between structural zones accommodating internal and external walls, in both plan and elevation to enable the standardisation of construction components.

- **Standardisation_** the manufacture of homegrown timber components will be performed by Kenton Jones Joinery providing an opportunity to test skill and tooling requirements, quality control, manufacturing efficiency, material waste and supply chain at a relevant scale of manufacture.

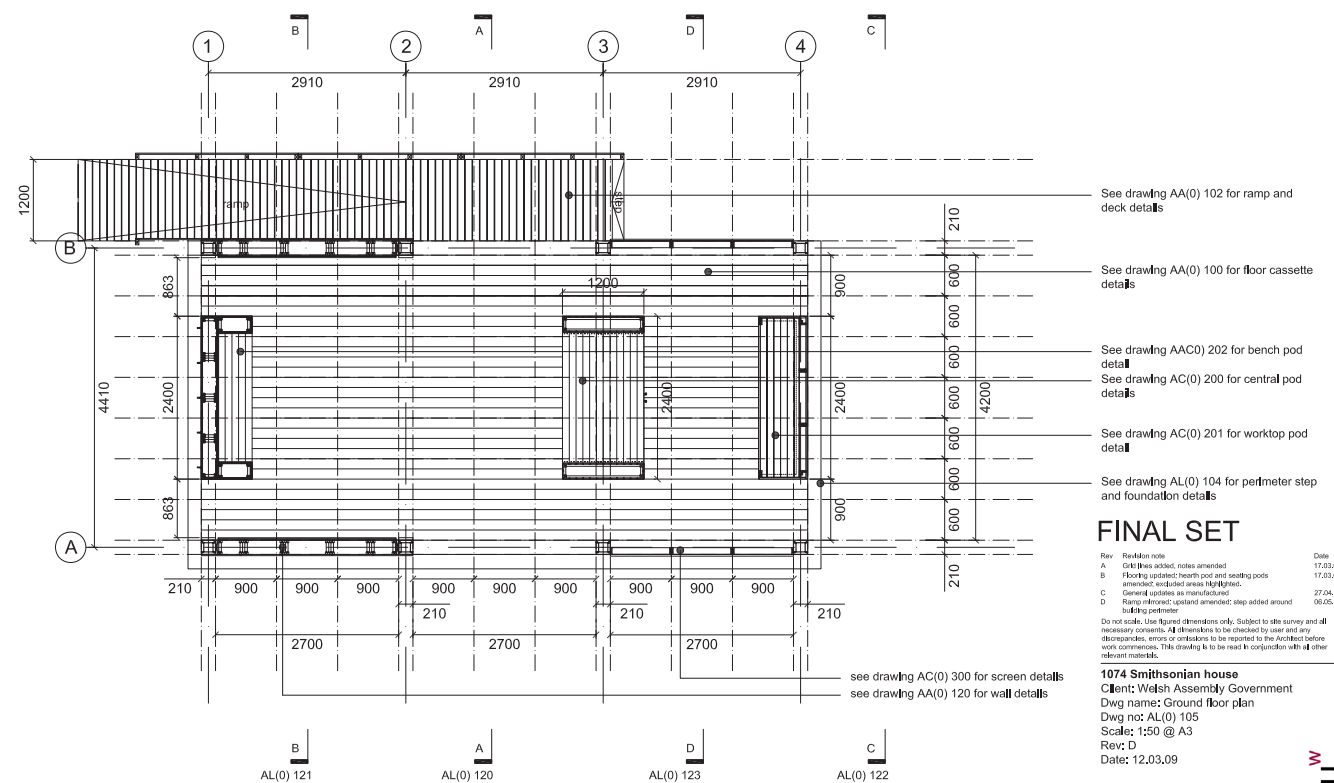


Figure 8.63: Ground floor general arrangement plan.

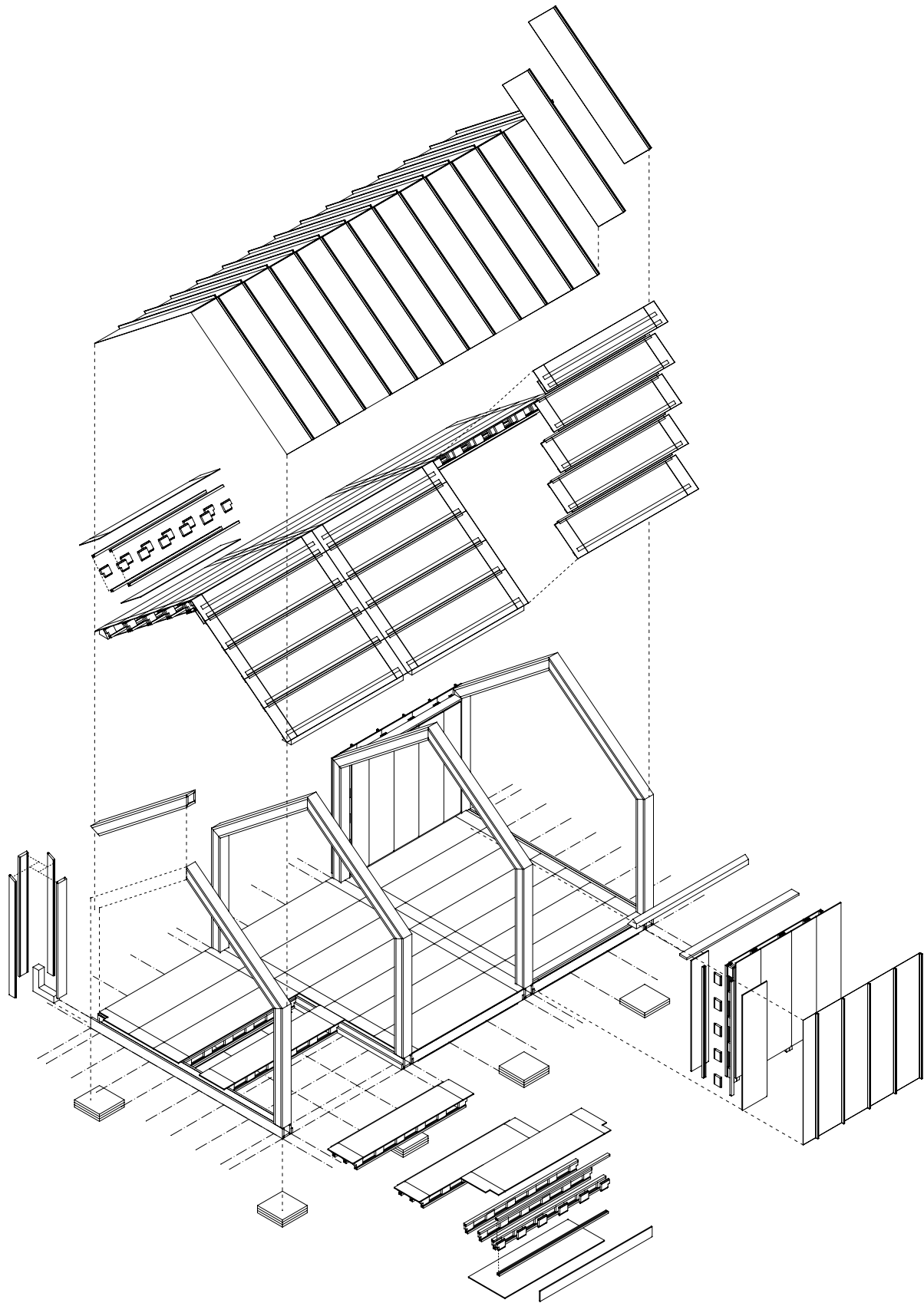


Figure 8.64: Assembly axonometric diagram of the pavilion
Source : Steve Coombs



Figure 8.65: Assembling bolt laminated angled connectors for the eaves junction of the primary portal frames.
Figure 8.66: Bolt laminated connectors.
Figure 8.67: Ground floor box section beams with notched ends to receive connectors.

CONSTRUCTION/BUILDABILITY

- As the structure is to be assembled, disassembled and transported to USA for reassembly, the weight and ease of assembly of prefabricated panels, using limited mechanical assistance, is critical to the success of the project. Of particular interest is the dimensional tolerances of manufactured components and the accuracy of on site assembly. Durability and robustness of prefabricated components during transportation and storage are also key.

REFLECTION

- Economic evaluation_ to assess the affordability of the system incorporating a higher percentage of home grown prefabricated components.
- Public Response_ Of particular value, the project will provide a unique opportunity to test public response to the housing system, and the use of homegrown timber components. The user response to items such as housing type, scale, finishes and organisation is incredibly valuable for future development of housing types for the open market, and the potential market response to homegrown timber components.

8.04.2 COMPONENT DESIGN

The realised proposal was a simple, and predominantly open, pitched roof pavilion consisting of three structural bays. The East bay of the pavilion offers a degree of enclosure and protection from the weather in the form of OSB based wall panels and bench unit, providing an area for exhibiting material.

The pavilion provided an opportunity for the Project Team to develop a structural panel system for floors, walls and roofs based for the first time on a Sitka spruce ladder beam in combination with OSB. Internally, homegrown Sitka spruce tongue and groove and large section timbers are used to finish surfaces and construct a number of space defining furniture units including a central 'hearth' providing a high desk and bench seat.

The box section frame is arranged as portalised pitched frames at 2910mm centres. The pavilion has an internal span of 4.2m and an eaves height of 2.4m. Each portal is assembled of 5 210x210mm box sections. Roof beams and columns are mitred to give a roof pitch of 38 degrees. The beams and columns are jointed using solid section connectors fabricated of 5 bolted laminations; two 45mm cheeks of Sitka spruce provide depth for screw fixings driven through the box section frame, and two layers of 10mm steel sheet, separated by a 20mm layer of timber packing, are cut and welded to the proposed frame angles, see figures 8.65 - 8.66. Steelwork is incorporated into the connector design in order to provide additional mass and counteract concerns of uplift in the hurricane risk area.



Figure 8.68: Construction sequence on the Washington Mall

FROM TOP LEFT ACROSS - DOWN

- a) Portal frame assembled horizontally on ground.

b) Portal frame lifted to vertical using a forklift and set on concrete block footings.

c) Second portal assembled on ground.

d) Portal frames set out at 2.7m centres with eaves beams spanning between providing temporary stability.

e) Floor infill panels of Spruce ladder beams with OSB sheathing installed between portal frames.

f) Floor installed.

g) Roof infill panels Spruce ladder beams with OSB sheathing installed between portal frames.

h) Roof panel installation continued and internal fit out commenced.
- i) Standing seam steel system applied to roof.

j) External wall infill panels installed

k) Hit and miss shuttering applied to open bays and internal finishes installed.

l) Finished pavilion.

The secondary structure employs the Type 01 Ty Unnos Sitka Spruce ladder beam developed by Burroughs and KJJ for the Elements Europe Modular product. At a 2.7m clear span, the ladder beam is at its span limit therefore ladders are required at a maximum centre of 300mm. Ladder beams are combined with sheathing boards of OSB to the internal and external surfaces to form prefabricated panels. Panel designs are described and illustrated further in Appendix B3.

8.04.2.1 FLOOR PANELS

Each bay of the floor is constructed using 7 cassettes spanning between portal frames, arranged within a 600mm grid. The cassettes are designed to slot into the primary structure from above with notched ladder beams landing and fixing directly onto a plate of 100x40mm Spruce. 18mm OSB sheathing boards overlap and underlap along the panel edge to the interior and exterior enabling panels to land and make connection directly into the ladder beams of neighbouring panels, see Fig. 8.73. This requires 3 types of cassette, including an extra wide edge cassette, notched to fit around the structural frame, and a centre cassette which is the final cassette to be installed.

8.04.2.2 WALL PANELS

Each 2.7m wide by 2.4m high wall opening is infilled with 3 cassette types. All are arranged vertically and installed from the exterior of the frame to abut a sole plate fixed to the installed floor cassettes and a top plate fixed to the underside of a solid section eaves beam. Externally 9mm OSB overlaps the ladder length top and bottom to provide fixings points directly between the cassette and the frame. Two edge cassettes are designed with an extended outer sheet of OSB to overlap the box section frame with fixings made through the overlap in to the spruce column. Once again the central cassette is the last to be installed.

8.04.2.3 ROOF PANELS

In a similar manner to floor panels, roof panels are slotted into the primary structure from above, spanning 2.7m between portal frames. Each pitch requires three different panel types set out predominantly to a 600mm dimension. An eaves cassette is installed first with an outer leaf of OSB extended to the eaves line. Standard 600mm wide panels make up the majority of the pitch with a ridge cassette cut to width to complete the remaining section of the roof pitch.

The detailed design of the Pavilion can be seen in more detail in Appendix B3.

8.04.3 MANUFACTURE AND CONSTRUCTION

During design development the decision was made to prefabricate all elements of the construction and perform a test assembly prior to transporting the building to the USA. This process was carried out across two sites.



Figure 8.69: Prefabricated infill panels awaiting installation with notched ladder beam and external OSB sheathing.

Figure 8.70: Notched ladder beam of roof infill panels located onto a bearing plate fixed into the primary portal frame.

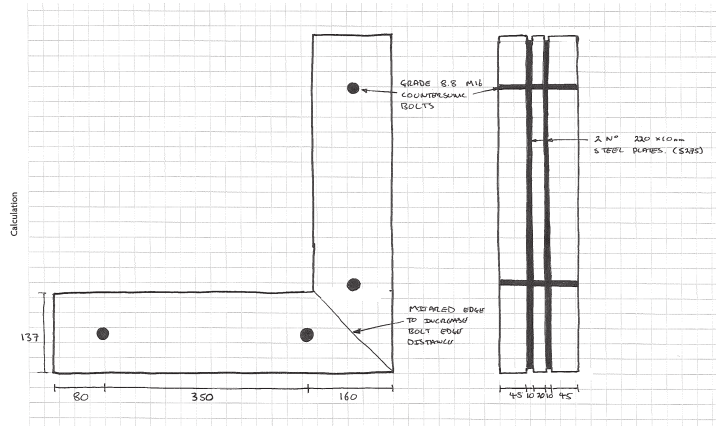


Figure 8.71: Laminated timber and steel connectors.

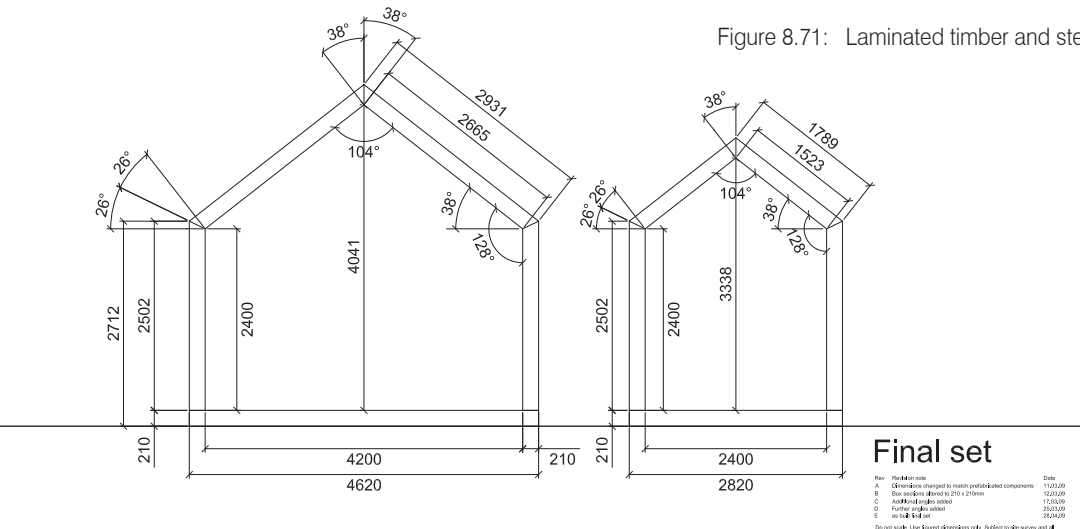


Figure 8.72: Primary structure manufacturing diagram.

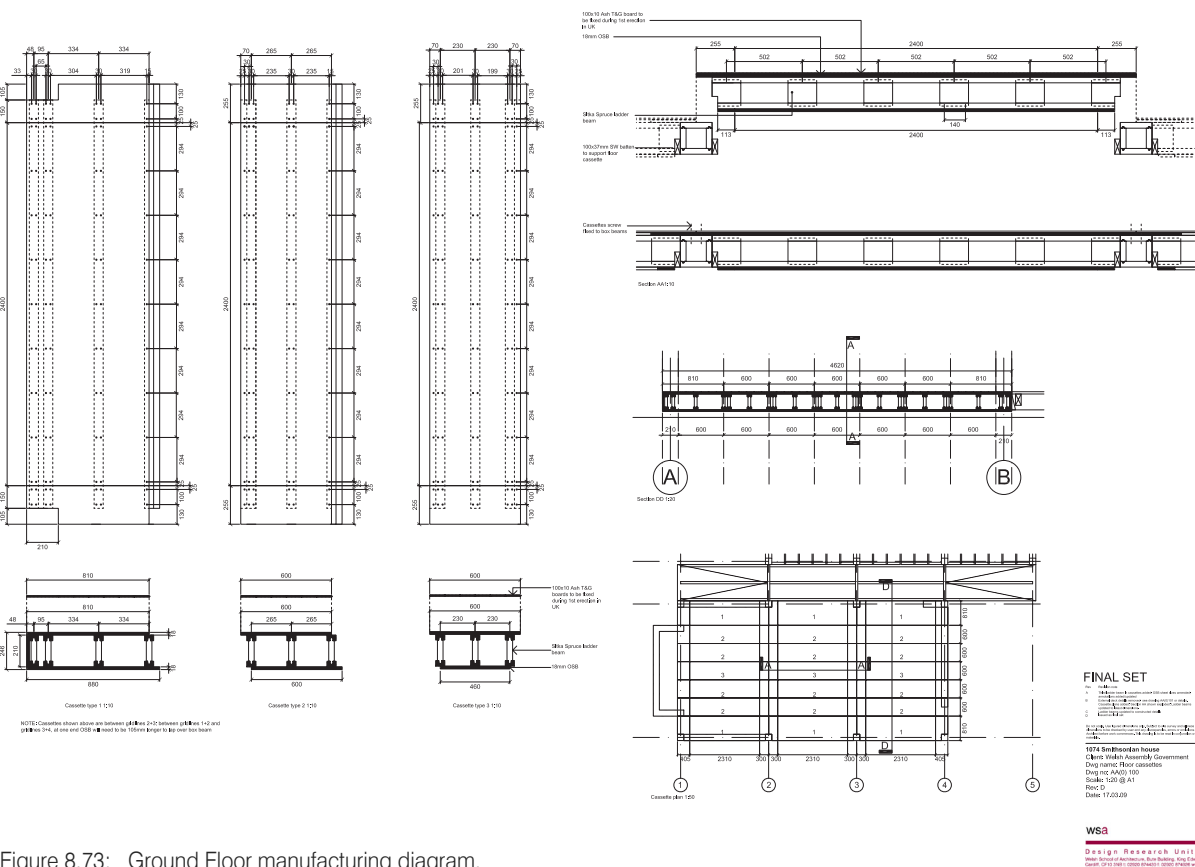


Figure 8.73: Ground Floor manufacturing diagram.



Figure 8.74: Portal frames assembled in warehouse.

Figure 8.75: Floor and roof panels being installed.

Figure 8.76: Completed structure awaiting claddings.

Figure 8.77: Pavilion was then disassembled and loading into a container for transportation to Washington.

Type 01 homegrown timber ladder beams and box section portal frames were manufactured at KJJ's joinery workshop in Welshpool employing the manufacturing process as described in Fig. 6.49. In addition to this process, ladder beams are notched to each end from the web centre line to the bottom flange, to provide a bearing down onto the prefixed bearing plate.

Once manufactured, components were transported in stick form to a warehouse in Chirk where a team of carpenters combined the engineered ladder beams at appropriate centres with 9 or 18mm OSB sheathing boards cut to the correct width. Sheathing boards are fixed directly into the ladder beam flange with fixings at 300mm centres. Fabrication was carried out in parallel with the assembly, enabling the team to test and adjust components as necessary throughout the process. The relative simplicity of the processes involved in this assembly were counteracted by the number of panel types required to ensure that panels could be assembled in sequence within the portal box beam structure. The large number of panel types, and the differing quantities of each type led to confusion and inefficiency during manufacture.

As the pavilion was not required to provide a thermal envelope, panels and box beams did not receive insulation.

PRIMARY STRUCTURE

During assembly in Chirk, and then in location on the Mall, the portal frames were laid out and assembled flat on the ground prior to being lifted to their vertical position. Box beams were arranged and solid connectors inserted into place. Once loosely assembled with all connectors in place, the joints could then be checked using templates, adjusted and fixed in place. A forklift was employed to lift the frame to a vertical position, where fixings into the temporary substructure hold the frame upright. Once multiple frames are in location, solid profiled laminations of spruce, spanning between portal frames, are located onto prefixed shear plate connectors installed at eaves level.

The assembly process raised few concerns however, once vertical, portal frames were found to splay. This settlement was put down to the weight of the connections and roof infill panels causing rotation at the joints. It is believed that this rotation is due to the tolerances between the solid connector and the hollow box section and a small amount of shear slippage in the screwed connections with the soft timber cheeks of the connector. The flex in this connection became further exacerbated with each subsequent reassembly of the pavilion as screws were driven back into previously cut timber. For the pavilion's final assembly at the Royal Welsh Showground, a line of glue was included between box section and connector which successfully increased the rigidity of the joint. In order to restrain the splaying of the portals, a 210x40mm solid section tie beam with

chamfered ends was introduced at eaves level in each gable end, and fixed using 100x100mm steel angles.

SECONDARY STRUCTURE/ THERMAL ENVELOPE

As previously described, in order for panels to make direct contact with neighbouring panels, they are detailed with overlapping and underlapping sheathing boards and designed for assembly in a specific order from the outer most edges of the primary structure. Panels are made to a very high tolerance and require the primary frame structure to be accurately located parallel and perpendicular to allow panels to fit efficiently. Ground floor panels were therefore installed in conjunction with the locating of portal frames, acting as a method of accurately setting out the frame positions prior to the permanent fixing of the primary structure.

Despite the number of panel types required, the assembly method was generally straightforward. In each case panels are installed from the edge of the opening to the centre with the centre panel acting like a key stone. The notched ladder and bearing plate detail enables panels to be dropped into place, with the weight fully supported on the bearing plate and then slid and manipulated to the correct location as required. This proved particularly useful for the installation of roof panels as the detail ensured panels were reasonably secure as soon as they were located on the bearing plate without the requirement for any fixings.

8.04.4 OBSERVATIONS

8.04.4.1 COMPONENT DESIGN + CERTIFICATION

STRUCTURAL ORGANISATION

- The primary structure, designed as a series of portal frames was accurately and efficiently assembled at ground level before being lifted into location using a forklift truck. Once vertical however the two dimensional frame is prone in the third direction. The solid section eaves beam provided a simple support, connecting portals together and acting as an eaves plate for the installation of wall and roof panels. Its fabrication however was complex and inefficient, requiring small sections of timber to be glue laminated together and planed to a wedge shaped section. The lack of any additional primary structure in the spanning direction resulted in a complicated floor panel design which required specific edge panels, with ladder beams doubled up on the perimeter edge, to support the weight of wall panels and panels notched around columns.
- Spreading of the portal frames when fully loaded is a concern. Once insulated and clad the weight of the roof will increase significantly and the level of frame distortion witnessed in the pavilion would not be considered

acceptable in reality. The inclusion of a tie beam in the pitched portal frames at eaves level of the gable ends suitably reduced the spreading of the frame whilst also squaring the structural opening for infill panels. Spatially however these beams are not desirable in the main body of the pavilion where the unobstructed roof space is a clear design asset. The introduction of more suitably connected OSB panels will also significantly reduce the spreading of the frame. The assembly method must therefore be carefully programmed to ensure the frame is not extensively loaded at roof level prior to the frame being suitably restrained.

STRUCTURAL FIRMNESS

- Perceived firmness is a factor that is often cited for the reduced appeal of timber frame construction, suggesting a reduced robustness or durability. Although designed within the tested limitations of the components the panels did display an amount of movement once assembled. This was particularly noticeable with the perimeter panels which received a large amount of foot traffic at access points. A potentially significant factor in this assessment however is the lack of infill, such as insulation, within panels which will act to deaden acoustics and vibrations.

8.04.4.2 BUILDING DESIGN

FINISHES

- All structural components and internal finishes were formed using homegrown timber resources. There were few reports of issues sourcing homegrown timber or concerns in regards to quality. It was noted however that the softwood sourced for the project displayed wide variation in moisture content and required further drying. Although some selection and sorting was required, the consistency in colour and knot content was pleasantly surprising.

8.04.4.3 DETAILED DESIGN

DIMENSIONAL COORDINATION

- Although panels were designed to a 600mm dimensional grid, the overlapping and underlapping of sheathing boards within this dimensional organisation resulted in many of the sheathing boards being cut to sizes not related to the 600mm dimension, see Fig. 8.73. This significantly limited the intended material efficiencies associated with the chosen dimensional grid and largely made it irrelevant. This was further exacerbated by the design decision to set frame centres at 2.91m, giving a floor and roof panel span of 2.7m. Each panel therefore required short lengths of sheathing boards to complete the full panel length.

STANDARDISATION

- The infill panel design achieved a very limited level of standardisation with each infill element requiring a minimum of three different types to incorporate sheathing boards that overlap the primary structure and bear directly onto the ladder beams of neighbouring panels. This results in a large number of different design scenarios.

8.04.4.4 MANUFACTURE

- The provision of fixings was a primary complaint from the assembly team, both in terms of cost and ease of assembly. Of particular note are fixings required on site for installing through the infill panel and notched ladder beam into the timber bearing. The length and diameter of these fixings were incredibly substantial and each screw therefore required a pilot hole drilled during the test assembly.
- The design of infill panels with overlaps or underlaps to each long edge made panel assembly less efficient as ladders could not be simply aligned with panel edges and fixed without measurement or a form of assembly jig.

8.04.4.5 CONSTRUCTION/BUILDABILITY

- Generally the weight and scale of infill panels and box frame components could be safely handled by two people. Once combined with the timber and steel connectors, the portal frames however had to be moved using a forklift. Assembly of the primary structure flat on the ground substantially reduced the need for working at height and a small scaffolding tower was only required for the installation of the roof panels and finishes.
- On site the assembly of the primary structure including the installation of eaves beams could be completed in 3 hours by a team of 2-4 and the intermittent use of a forklift. In total the pavilion took just 9 hours to assemble, including the installation of timber flooring, metal roof and wall cladding and prefabricated timber shutters.

8.04.4.5 REFLECTION

ECONOMIC EVALUATION

- The project developed in an interrupted and somewhat haphazard manner financially due to the limited funding available for the project. The project was therefore significantly adjusted and scaled back throughout the programme including during the manufacturing process. In addition a large amount of the budget was required to support transportation, assembly and disassembly on site, production of exhibition material and manning of the pavilion throughout the two week festival period. In total approximately



CLOCKWISE FROM TOP LEFT

Figure 8.78: Gable end of hit and miss shutters required some temporary measures to resist some terrible weather conditions.
Figure 8.79: Central 'hearth' of Sitka spruce.
Figure 8.80: Hit and miss shuttering
Figure 8.81: The pavilion during the festival.

£38,000 was spent on the festival. It is estimated that £25,000 of this is directly associated with the manufacture and construction of the building including cladding, furnishings and finishes. This equates to a build cost of approximately £650 per m². This includes the manufacture of an additional primary structure suitable for an area of 25 m².

- The reconstruction of the pavilion at the royal Welsh showground including the provision of a completed watertight envelope with external membrane, cladding, internal finishes and glazed openings cost a further £12500 taking the total build cost to approximately £37500, equating to just under £1000 per m². This evaluation is approximate and has limited usefulness due to a number of known inaccuracies.

PUBLIC RESPONSE

- The project was deemed a success by the Project Team, whom received considerable media interest prior to its transportation to Washington, and great support from the WAG and general public once erected at the festival. Although the use of homegrown timber is the fundamental basis of this interest, considerable interest is generated regarding the potential to develop construction skills associated with the system. The relative ease of assembly displayed at the festival successfully reinforces the idea that a system of this type might appeal to new non-construction based individuals and enable them to develop construction skills.
- As the realised pavilion bore little resemblance to a complete house type the project did not enable the Project Team to test public response to the scale and form of house types. However the general public responded well to the form of the pavilion specifically identifying the ability to open up the main spaces into the unobstructed roof space as a valuable asset.

8.05 FUTURE WORKS WELSH PASSIVE HOUSE
THE WORKS, EBBW VALE

PROJECT SUMMARY

Architect Design Research Unit Wales
Client Blaenau Gwent County Council
Main Contractor G Adams Construction
Manufacturer Kenton Jones Joinery
Completed July 2010
Value £250 000
Contributions include
planning application support,
presentation images and modelling,
detailed design and production
information including Passivhaus
Standard, support and monitoring of on
site construction.



The Welsh Passive House at The Works in Ebbw Vale has been designed by the Design Research Unit Wales (DRU-w) for Blaenau Gwent County Borough Council (BGCBC) using Ty Unnos Sitka Spruce construction components. The sustainable building combines low cost Welsh timber, high levels of insulation and a state of the art heating and ventilation system to provide an environmentally friendly and innovative building.

The Future Works Housing Competition 2009 invited the design and construction industry to create the “Welsh Passive House” through the consideration of natural resources, climate and geography to determine the most appropriate delivery of a low energy and carbon house for Wales.

A 3 bedroom submission by DRUw was successfully awarded third place by the competition jury and the Project Team were invited in January 2010 to deliver the competition entry on a neighbouring site. The proposal would initially open as a temporary visitor centre to the Future Works housing site, for the National Eisteddfod at Ebbw Vale in July 2010 before conversion to a fully habitable home.

The house establishes the complex brief of combining the German PassivHaus performance specification with a desire to locally source labour, and materials within Wales, in addition to meeting the Welsh Design Quality Requirements and Lifetime Homes. Working with local builder G Adams and the BRE, local suppliers, and manufacturers have been integrated into the project and assistance given in the development of Welsh products towards meeting the stringent criteria of PassivHaus. This includes the development of a Welsh timber window intended for PassivHaus certification. It is also proposed that the house will meet CSH Level 5.

OPPOSITE PAGE

Figure 8.82: The Welsh Passive House at the Future Works.

8.05.1 DESIGN BRIEF

The original competition brief initiated by The Works: Ebbw Vale and BGCBC identified two alternative plots for the Future Works housing development. Plots 1 and 2, a 2 bed starter affordable home and 3 bed family property respectively, were proposed as a showcase for sustainable best practice, initially open to the public for a period of two years before becoming available for occupation. The design brief included;¹

- Buildings must be between 2 and 4 storeys high,
- There is no restriction on floor area within the determined plot boundary however the design must be compliant with the DQR Standard,
- Make use of local/sustainable materials to comply with the Works sustainability criteria including 100% sourcing of materials with Green Guide rating of B or above,
- Achieve CSH level 5 and meet the Passivhaus Standard of less than 15kWh/m².Yr space heating requirement
- Construction costs per m² should not exceed £1200 per m² excluding proposed Photovoltaics and land costs,
- To be delivered by July 2010.

The revised design brief for Plot 6 proposed a two bedroom detached house to meet the original competition brief with the additional requirement of employing the Ty Unnos construction system. The project is proposed as a temporary visitor centre for the Future Works housing development, hosting an exhibition and meeting room for a period of at least six months before being made available for private sale.

The project budget was also revised to a fixed sum of £250,000 including fees.

8.05.2 LEARNING OBJECTIVES

Following the completion of the ERC, the Welsh Passive House provided the Project Team with an immediate opportunity to respond to the findings of the previous proto-typical studies and apply further developed homegrown timber engineered construction components. As an affordable housing scheme, the project offered the first opportunity to apply research and design studies into space, design and quality standards.

COMPONENT DESIGN + CERTIFICATION

- Structural Organisation_ the structure will employ a post and beam homegrown timber frame with diaphragm infill panels, giving an opportunity to test the detailing, manufacture and assembly requirements and design

1 The Works: Ebbw Vale, *Future Works Housing - Welsh Passive House Design Competition* (Ebbw Vale: The Works, 2009), p. 9.

opportunities/ limitations associated with OSB diaphragm panels,

BUILDING DESIGN

- Design_ the project is the first application of the design pattern book research providing an opportunity to test the appropriateness of scale and form for housing, specifically focused on space standards, current permissible component performance and the 600mm dimensional organisation.

DETAILED DESIGN

- Detailed Design_ the project will develop the detailed design of homegrown timber components in the form of prefabricated panels for installation on site in conjunction with locally sourced natural insulations.
- Dimensional Coordination_ the project will employ a 600mm dimensional grid between structural zones accommodating internal and external walls, in plan and elevation to enable the standardisation of construction components.
- National House Building Council_ the project will need to meet market conditions for new build housing therefore the project will approach NHBC for consideration under the NHBC Buildmark warranty scheme.
- Environmental Performance_ The project offers the opportunity to test and monitor the appropriateness of the Ty Unnos component build system to performance standards that push beyond current industry practice, specifically the Passivhaus Standard and CSH.
- Finishes_ the project will test the system's adaptability to standard house building practices including; service distribution, underfloor heating and radiators, alternative internal and external surface finishes including tiles, dry linings, timber, and render,

MANUFACTURE

- Manufacture_ the manufacture of homegrown timber components will be performed by Kenton Jones Joinery providing an opportunity to test skill and tooling requirements, quality control, manufacturing efficiency, material waste and supply chain at an increased scale.

CONSTRUCTION / BUILDABILITY

- Buildability_ a constrained programme will test the buildability of the construction system in comparison with the ERC.

REFLECTION

- EconomicEvaluation_ to assess the affordability of the system incorporating a high percentage of home grown prefabricated timber components.



Figure 8.83: Street view of north-east elevations.

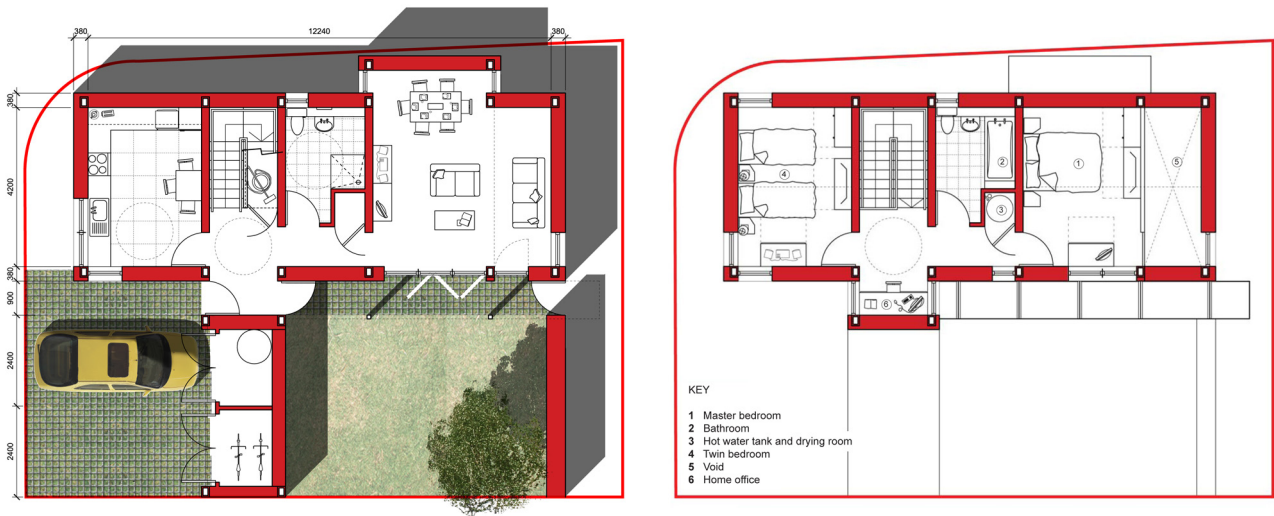


Figure 8.84: View of entrance and private driveway.

Figure 8.85: Ground floor plan.

Figure 8.86: First floor plan.

Figure 8.87: South Elevation.

8.05.3 DESIGN

The design of the Welsh Passive House draws inspiration from a number of key ideas prevalent in the local context of Ebbw Vale and the surrounding valleys. The organisation and form of the proposal draws on the traditional vernacular of the Welsh longhouse. Accommodation is distributed in a simple linear arrangement orientated east to west with a central core of circulation. This vernacular precedent is carried through into a simple palette of external materials, updated to make best use of contemporary local resources. Vertical timber cladding is combined with simple white render and a dark standing seam roof.

The simple linear pitched roof form of the longhouse is broken by two flat roof additions accommodating the primary entrance and home office to the south and living space to the north, articulated in bold colour themes, adaptable to the occupier's wishes.

The proposal embraces the Passivhaus philosophy of wrapping up to the north and opening to the south, with the main living spaces and first floor bedrooms opening to the south facing garden. A high performance thermal envelope is combined with a highly efficient mechanical ventilation system with heat recovery which supplies fresh air throughout the house drawing 90% of the heat provision from the outgoing exhausted air.

The design team have embraced the Works' sourcing philosophy, making use of locally sourced Welsh products throughout the build, including homegrown chestnut cladding and triple glazed thermally broken windows, Welsh sycamore flooring, staircase and furnishings, Welsh slate, recycled newspaper and wood fibre insulation.

8.05.4 COMPONENT DESIGN

The initial proposal put forward in March 2010 was the use of engineered homegrown timber components throughout as a whole house construction system in conjunction with low impact footings such as concrete pads foundations. This would include a two storey homegrown timber box section post and beam frame with integral roof trusses, a suspended timber ground floor and intermediary floor of prefabricated infill panels using Type 01 Ty Unnos ladder beams with OSB/3 sheathing boards, and prefabricated open wall and roof panels using the Type 01 ladder beam with external OSB/3 sheathing, and internal sheathing applied on site. This was quoted by KJJ, see Table 8.2, at a cost of just over £450 per m², without the inclusion of insulations.

In order to fulfil the brief, NHBC were approached early in the project and discussions began regarding the detailed design of structural timber in relation to ground level.

Component	Description	Initial Costing 18 03 10	Revised Costing 24 03 10	Revised Costing 26 03 10	Anticipated Final Account 04 05 10
Frame	Box Section Frame	£ 19,412.00	£ 19,412.00	£ 19,412.00	£ 18,132.00
	Steel and Timber Connectors	£ 6,200.00	£ 6,200.00	£ 6,200.00	
Floor	Floor Cassettes of Ty Unnos Ladders and OSB/3	£ 7,820.00			
	Ground Floor Joists in 1200mm OSB Cassettes		£ 2,866.00		
	First Floor Joists in 1200mm OSB Cassettes		£ 2,866.00		
	Second Floor Joists in 1200mm OSB Cassettes		£ 1,433.00		
	Floor Joists GF&FF Solid C16 Spruce			£ 1,800.00	
	Joist Hangers			£ 400.00	£ 1,632.00
External Walls	Wall Cassettes of Ty Unnos Ladders and OSB/3	£ 20,740.00	£ 15,221.00	£ 6,838.00	£ 11,632.00
	Studded Panels without OSB			£ 6,838.00	
Roof	Roof Cassettes of Ty Unnos Ladders and OSB/3	£ 5,440.00	£ 5,228.00		£ 3,602.00
	Ladder and OSB Cassettes 1200			£ 5,228.00	
Total		£ 59,612.00	£ 53,226.00	£ 46,716.00	£ 34,998.00
Per sqm - 132 sqm		£ 451.61	£ 403.23	£ 353.91	£ 265.14
Options	Partial Assembly of frame offsite	£ 2,000.00			
	Assembly assistance on site (2 weeks - 1 man)	£ 2,250.00			
	Timber Treatment	£ 1,000.00		£ 1,000.00	
	Delivery			£ 500.00	
	Insulate Box beams	£ 500.00	£ 500.00	£ 500.00	
	For Concrete Ground Floor deduct		-£ 5,866.00	-£ 3,000.00	
Profit and Attendance					£ 3,500.00
On Site Works	Supply and fix 210/270mm x 60mm treated timber sole plate. Fixings to be M16 Threaded bar c/ w nuts and washers set at 1mtr centres and fixed with Hilti Hi Hit injection concrete or equivalent				£ 969.19
	Erect frame and panels on site				£ 9,240.00
	Supply and fix 43 No Galvanised Steel connecting plates to secure frame to sole plate				£ 1,349.00
	Supply and fix 18mm OSB to inside face off all internal walls				£ 2,490.83
	Form 2 No 150mm dia holes to each bay within all external and internal walls to allow Warmcell blown insulation to be injected. Recover holes on completion				£ 300.00
	Form 1 No 50mm holes to external box beams to allow Warmcell blown insulation to be injected. Recover hole on completion				£ 10.00
	Warmcell Blown Insulation to Wall and roof panels				£ 3,756.83
	Warmcell Blown Insulation to box beams				£ 536.55
	Warmcell Blown Insulation to internal walls				£ 500.00
	Rockwool Mineral Fibre Loft insulation packed into box beams on site				£ 500.00
Total		£ 65,362.00	£ 47,860.00	£ 45,716.00	£ 58,150.40
Per sqm - 132 sqm		£ 495.17	£ 362.58	£ 346.33	£ 440.53

Table 8.3: Comparison of quotations provided by Kenton Jones Joinery.

These initial discussions proved largely unhelpful with a general conclusion that all structural timbers must be suitably detailed at a minimum height of 150mm above ground level in order to be compliant with NHBC standards. If applied to the Ty Unnos post and beam frame with suspended timber floor, this would result in a finished floor level of 450mm above external ground level. Whilst it is possible to discuss and agree bespoke construction details with NHBC for acceptance within their warranty standards, it was advised that the process is time consuming and was not within the scope of the project programme. As a 450mm finished floor level posed considerable disabled access and construction issues, it was proposed that the suspended ground floor detail be replaced with a 350mm oversite slab with 750mm deep reinforced ring beam.

The post and beam frame was therefore conceived as a platform frame. At ground level 270x210mm single storey columns make connection with the concrete upstand using 200x150x10mm galvanised steel angle brackets. The first floor intermediary floor beams bear directly onto the column head, employing a T shaped steel and timber solid connector to connect ground and first floor columns with the first floor beam. Further steel and timber connectors are employed at eaves and ridge levels to create 6 portal frames, set at varying centres up to 3210mm. Portal frames are connected at first floor and eaves with spanning edge beams, bearing on simple shear/T plate timber connectors.

During the development of the project costing a number of permutations of component specification and levels of prefabrication were considered in order to meet the restricted budget. Initial costings provided by KJJ suggested that homegrown engineered timber components were considerably more expensive than alternative options such as JJI joists, and solid section joists. As a compromise it was decided that homegrown C16 timber joists would be employed throughout. It was proposed that the project would provide an ideal opportunity to assess the quality of standard homegrown C16 material against the feedback received from timber frame manufacturers.

Wall infill panels are designed as full bay prefabricated panels, consisting of a 210x60mm sole plate, 210x40m header and solid section studs in sections of 210x40mm and 210x60mm as appropriate, at maximum centres of 600mm. 18mm OSB/3 boards are applied as a sheathing to the exterior of each panel, with allowance for a minimum 40mm overlap of the post and beam frame on all edges. An internal sheathing of 18mm OSB/3 is applied on site with overlaps at the panel top and base ensuring direct connection into the primary structure from the foundation sole plate to the eaves beam. These panels, in conjunction with similarly detailed internal walls, provide all diaphragm resistance required by the long, thin and tall building. Open roof panels are similarly detailed, making use of solid section spruce joists spanning between primary structural trusses.

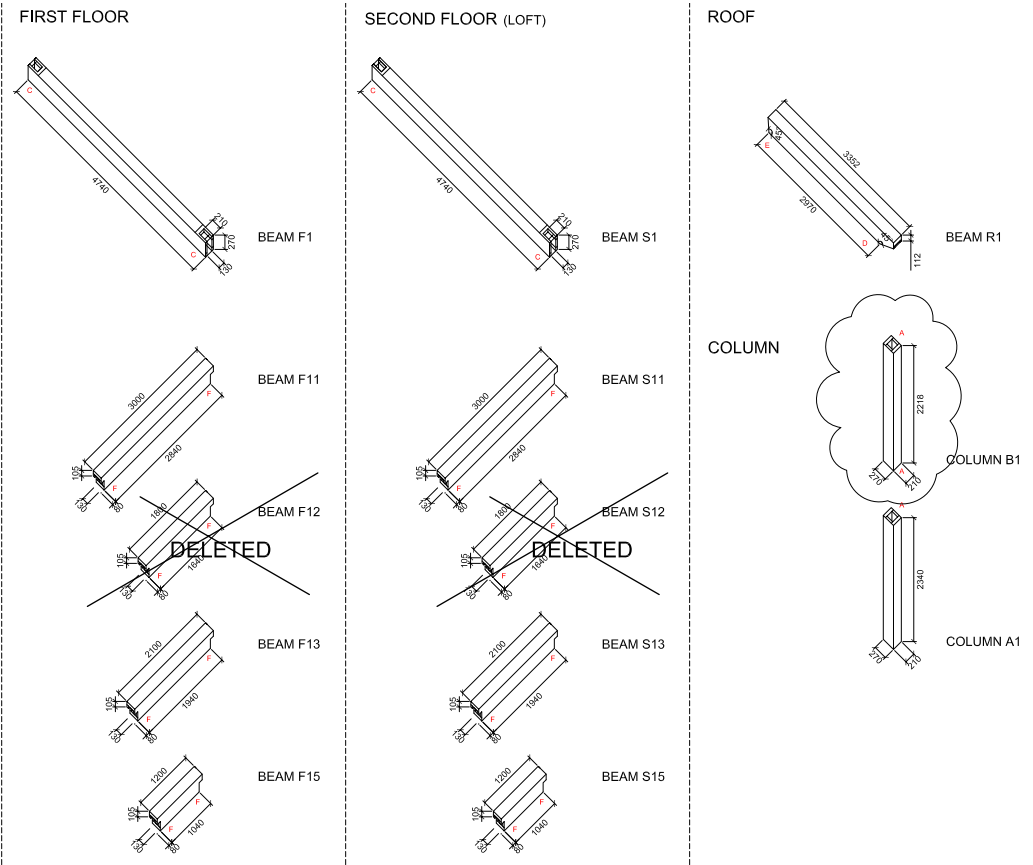


Figure 8.88: DWG AC (0) 118 Box section types, manufacturing drawing.

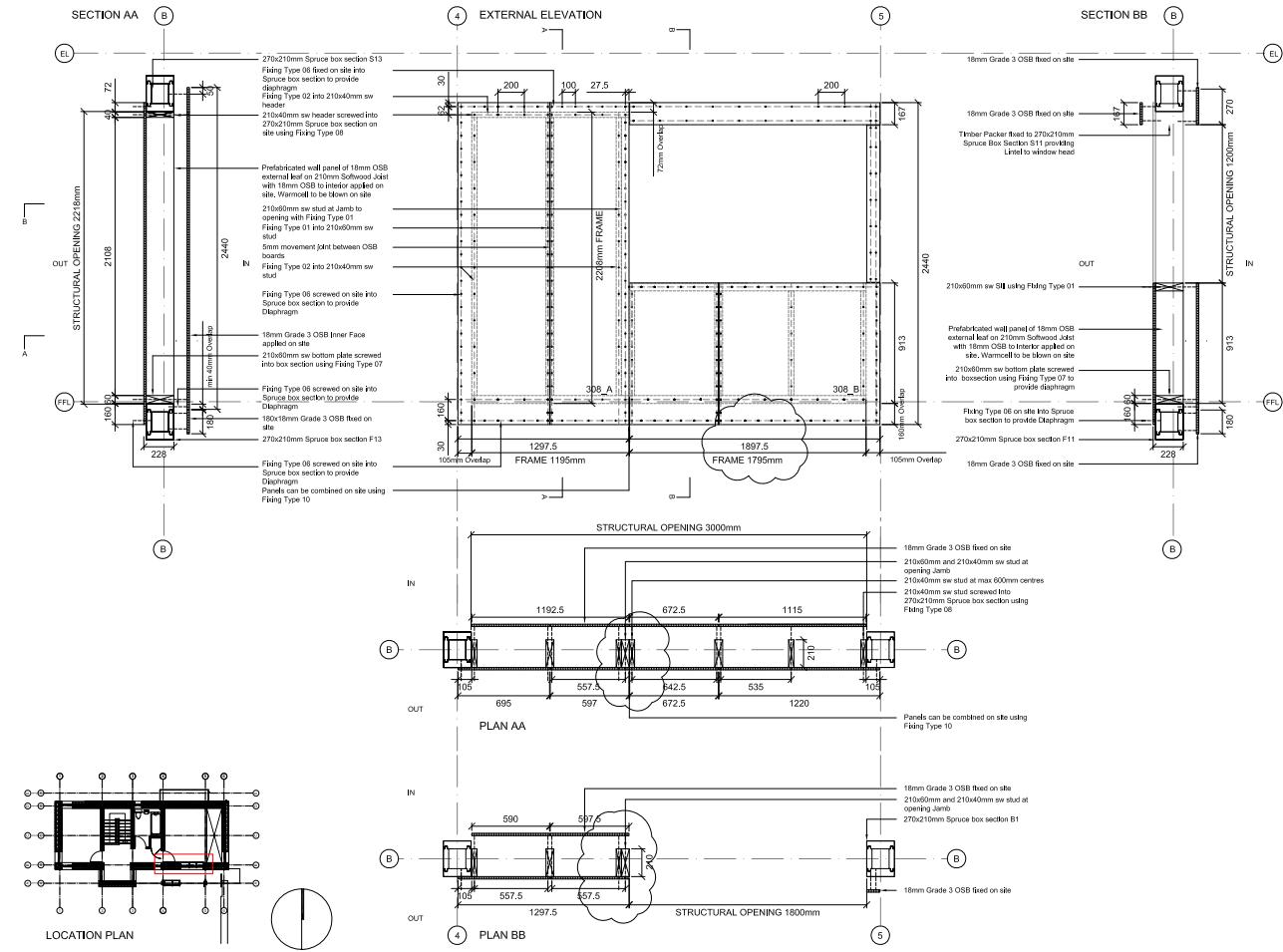


Figure 8.89: DWG AC (2) 308 Wall infill panel 308, first floor south wall to master bedroom, manufacturing drawing.

Intermediary floors, although originally proposed as 1200mm wide prefabricated cassettes, were supplied by KJJ as loose 210x40mm Welsh Spruce C16 joists, to be fixed on site using joist hangers at a maximum of 450mm centres. These are overlaid on site with 18mm T+G Weyroc Protect P5 board. As transverse internal and external walls are required as racking panels, the OSB/3 sheathing is required to make direct connection with the primary structure at all points from foundation to roof truss. Therefore the intermediary floor structure has been detailed to span between walls. Joists are installed after wall sheathings are completed, mounted into face fixed joist hangers, fixed through sheathing boards into the primary structure. This specification reduced costs by approximately 25% over initial quotations.

See Appendix B4 for a detailed specification.

8.05.5 MANUFACTURE AND CONSTRUCTION

Manufacturing drawings were generated by DRUw with guidance from Burroughs. This process was slow and laborious due to the large number of arrangements required. It was decided at an early design team meeting that panels would be assembled as complete bay sized 'open' panels with a single skin of OSB/3 attached to the exterior. Although it was desirable to the contractor to receive closed panels, the requirement to provide diaphragm connection with both internal and external sheathings in the form of frame overlaps made this very challenging to achieve.

In total 40 drawings were generated for the assembly of infill panels and a further 9 were generated for the manufacture of the box section structure and connectors. These drawings are supported by a Cassette Schedule, Frame Schedule and Fixing Schedule. In most cases each structural opening is approached as an autonomous scenario, with factors such as openings, location in plan and section, and structural specification, all determining the arrangement of stud centres, sole and top plates, OSB overlaps and fixings. The production of these drawings took approximately 16 days to draft, issue for comment and amend for fabrication.

Due to the differing requirements placed on panel design, typically due to the specification of racking panels, 14 alternative fixing types are required for the assembly and installation of panels. In order to simplify this specification it was proposed that all panels could be detailed as racking panels. The number and cost of additional fixings involved in this over specification was too significant to make it cost effective.

Initially Kenton Jones requested a minimum lead in time of 5 weeks for the manufacture of components including frame and infill panels. However it would be necessary to stagger a number of deliveries. Due to the number of amendments

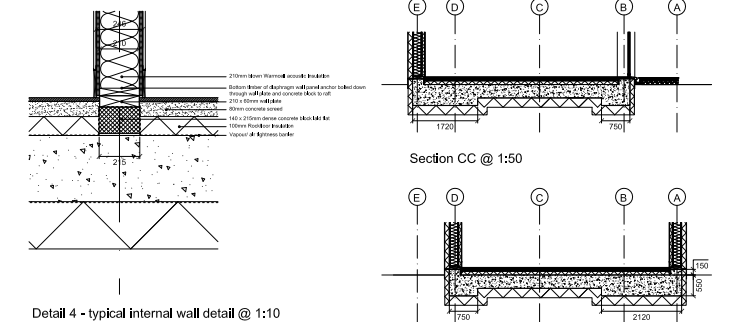
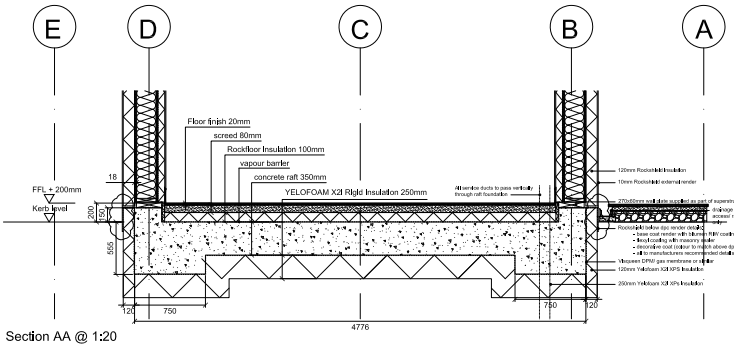
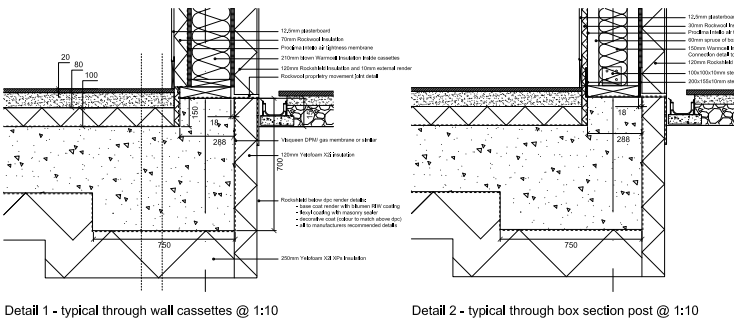
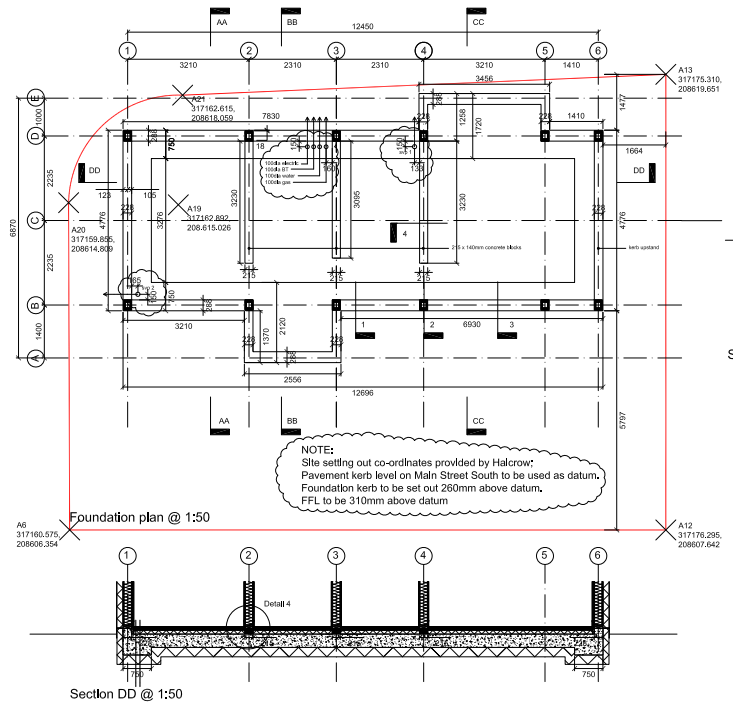


Figure 8.90: Foundation plan and details not to scale

OPPOSITE PAGE

- Figure 8.91: Formwork prepared for oversite slab.
- Figure 8.92: First three portal frames installed with temporary stays.
- Figure 8.93: Steel angles providing a direct connection between a column and the concrete slab. The fixings protrude into the structural opening to be infilled with windows and doors.
- Figure 8.94: Ground floor frame and infill panels installed.
- Figure 8.95: Open panels are installed from the exterior and sheathed on site with OSB.



made to drawings, final manufacturing drawings were submitted up to just 10 days before items of the construction were due for delivery. Delivery was made in three lots, with the primary structural frame and sole plate timbers delivered first.

During manufacture of infill panels Kenton Jones reported a significant quantity of rejected C16 material, specifically the smaller 210 x 40mm sections, due to distortion. Timber required planing and processing beyond a quantity acceptable for graded timber therefore, once processed, the timber could no longer be classified as C16 for structural purposes. Kenton also reported issues with sourcing the required quantities of graded material on tight timescales. He therefore proposed the assembly of Type 01 Ty Unnos ladder beams for use in the fabrication of roof and internal wall panels. Despite resulting in a more expensive option, this could make use of a significant quantity of the rejected material and subsequently enable KJJ to deliver roof panels to the required timescale.

8.05.5.1 SUBSTRUCTURE AND PRIMARY STRUCTURE

The connection between primary timber frame and the oversite slab foundations generated a number of conflicts. In the most part the foundation connection relied on galvanised steel plates and steel angles installed within the structural openings of infill panels to make a joint between an anchor bolted continuous sole plate and the box section columns, see Fig. 8.93. In order to accommodate the angles, infill panels and door frames in adjacent openings were notched to each affected corner, see Fig. 8.96. In the case of door openings this became a significant detailing issue with fixings protruding by over 25mm, resulting in significant adjustment of the frame and on site welding.

Fig. 8.97 describes the assembly process of the post and beam frame.

Figure 8.96: DWG AC (2) 308 Wall infill panel 308, ground floor south wall to hallway, manufacturing drawing.

- 18mm Grade 3 OSB Inner Face applied on site
- 210x60mm sw bottom plate screwed into sole plate using Fixing Type 09 in addition to M16 bolt connection. See Burroughs ssk009.
- 150x15mm Notch in Bottom Plate + side stud to receive steel angle Post Connector
- 270x60mm sw sole plate anchor bolted through DPC into concrete upstand at 1m centres. Anchor bolts to be countersunk to provide flush finish. See Burroughs ssk009.

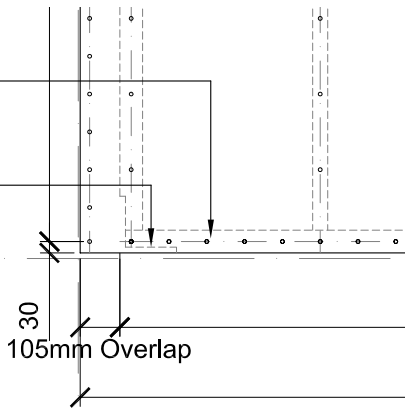




Figure 8.97: Construction sequence of the Passive House.

FROM TOP LEFT ACROSS - DOWN

- a) Site prepared for foundations.

b) Formwork and steel reinforcement prepared for ground bearing slab.

c) Foundations poured.

d) Single storey columns and intermediary floor beams assembled as a goal post and fixed into timber sole plate with spanning beams installed between.

e) With ground floor post and beam frame assembled, open infill panels installed.

f) The first floor post and beam frame with integral roof trusses and tie beams are
- assembled on the ground floor platform, and infill panels installed.

g) Lean to porch and dining bay are installed to complete the structural envelope and wrapped in breather membrane.

h) Internal sheathings applied to walls and windows and doors installed.

i) Warmcel insulation blown into panels and cladding wood fibre insulation applied to roof pitch.

j) Aluminium linings applied to surround openings, wood fibre insulation applied to
- first floor elevation and external insulated render system applied to ground floor and bays. Standing seam metal roof installed.

k) Render layers applied to insulations and solar panels installed.

l) Timber cladding installed to first floor elevation.

m) Rainwater goods and flashings completed.

n) External landscaping.

o) Finished house.



Figure 8.98: Intermediary floor joists installed on joist hangers face fixed directly to floor beam.
Figure 8.99: Metal straps across intermediary floor zone to connect diaphragm panels.
Figure 8.100: Living room internal wall with viewing panel to ladder beams.
Figure 8.101: Intermediary floor installed at loft level with roof trusses awaiting roof infill panels.

8.05.5.2 THERMAL ENVELOPE

Installation of the thermal envelope occurred in parallel with the assembly of the primary structure with ground floor open wall panels installed prior to the construction of the first floor primary structure. Full bay panels were lifted into location from the exterior, and slid into place to locate the overlaps of external sheathing boards against the exterior faces of the primary structure. Fixings are installed to the interior of the panel connecting the panel bottom plate to foundation sole plate and panel header to the intermediary edge beam. Fixings are also installed to the exterior, connecting sheathing overlaps directly to the primary structure. An internal skin of OSB was then applied to the installed panel and fixed as specified. This process was repeated for the installation of the internal diaphragm walls, with OSB sheathing boards lapping the intermediary floor beams.

The intermediary floor is installed as loose joists on face fixed joist hangers. On site this saw a departure from the proposed assembly process as it was intended that internal diaphragm walls would be installed at both ground and first floor prior to the installation of the floor joists.

The design of this detail was due to the need to transfer racking forces from one sheathing panel to the next from the foundations to the roof trusses. This is achieved by making direct connections between OSB sheathing panels into the intermediary floor beams. With floor joists installed directly into the primary structure, it was no longer possible to lap and fix first floor panels directly into the intermediary floor beams. This was subsequently resolved by installing metal straps into routed slots across the junction, see Fig. 8.99.

With internal sheathing boards installed and all joints taped, two 150mm diameter holes were formed into each bay of the external and internal walls to allow blown Warmcell insulation to be injected. These holes were then recovered and an internal lining of Intello airtightness and vapour barrier installed.

It took approximately 15 days to assemble the primary structure, install infill panels and apply internal sheathing boards on site. A further five days were dedicated to the installation of the airtightness membrane, including the taping of joints and the installation of windows and doors.

8.05.5.3 SERVICES AND FINISHES

The performance brief demanded an unusually complex mechanical and electrical specification. The typical wall build up integrated a dedicated service zone on the warm side of the airtightness membrane and structural panel, including a smaller depth zone across the internal face of the box section frame. This allowed services up to 30mm in diameter to be distributed around the perimeter of the house and between ground and first floor. A service core at the centre of the



OPPOSITE PAGE

Figure 8.102: Looking up from the living room into the double height master bedroom void.
Figure 8.103: Ground floor bathroom window, taped and sealed.
Figure 8.104: Airtightness membrane installed between panel and sole plate.
Figure 8.105: Intello membrane applied and taped around the spanning tie beam in the master bedroom and the south opening.

house distributes larger service requirements vertically, including fresh and stale air supplies to the primary living spaces. The greatest benefit of this distribution is the limited need to penetrate the airtightness membrane during first fix, with just mains connections breaking through this membrane. The result is an airtightness performance of 0.25ach @ 50 Pa.

Distribution of services within internal walls however proved to be considerably more disruptive. During panel design it was decided that solid studs would be replaced with Ty Unnos ladder beams in the internal lateral wall panels to ease the distribution of services. Large areas of the prefixed sheathing was therefore cut and removed during first fix to allow access thus effectively removing the racking potential of the panel.

To the exterior of the structural envelope a further 120mm of rigid insulation was applied to all elements. This ensured U-values of 0.11 W/m2K and 0.10 W/m2K were achieved for walls and roof respectively. An insulated render was applied to the ground floor and bays, whilst a homegrown vertical sweet chestnut cladding was applied to the first floor. A roof finish of standing seam metal was profiled at eaves to incorporate hidden gutters.

8.05.6 OBSERVATIONS

8.05.6.1 COMPONENT DESIGN + CERTIFICATION

STRUCTURAL ORGANISATION

- In general the structural frame design posed few challenges during manufacture and assembly. However the assembly of roof trusses using solid section connectors installed into the hollow of each junction emerged as a potential problem. With any order of installation, the geometry of the truss results in one connector unable to be installed in the assembled triangle. A number of solutions were identified including the removal of a section of the web or flange to allow the ridge connector to slide into location and be fixed. Although this would reduce the capacity of the junction it was suggested that the bottom flange of the box section could be removed at the ridge without significant effect on performance.
- The inclusion of a tie beam at eaves within the 'portal' primary frames significantly simplified the detailing and manufacture of infill panels in gable ends and internal walls. In the most part they had little spatial effect on the realised design as they fell within wall constructions. At grid line 5 however the tie beam falls between the master bedroom and void leaving the 270 x 210mm beam exposed, see Fig. 8.113. This is unfortunate in the open roof space and the omission of tie beams should be considered for future open plan spaces.



OPPOSITE PAGE

- Figure 8.106: OSB panelling removed to an internal wall to allow passage for underfloor heating pipes.
- Figure 8.107: Kitchen with battens applied to the service void and first fix started.
- Figure 8.108: Rockwool flexi infilling the battened service void to the master bedroom.
- Figure 8.109: Battening of openings in kitchen.

8.05.6.2 BUILDING DESIGN

DESIGN

- In general the Passive House has been very well received by the client and general public. Its long and thin form is strikingly different to typical volume house builder type units and provides an optimal arrangement for passive design due to large areas of south facing glazing.
- The 600mm dimensional arrangement has created a number of conflicts in plan, specifically in the design of the stair core. During detailed design it emerged that, once finished and a stairs erected with suitable handrail, it would not be possible to satisfy Requirement M1 of the Building Regulations within an 1800mm bay as stair flights must have a clear width of 900mm. A deviation from the 600mm grid was therefore required with the stair bay increasing to 2100mm.
- In elevation however the organisation of openings within this 600mm grid has proved successful.
- As discussed previously in Chapter 7.0, a permissible span of 3.0m is restrictive in the design of Space Standard complaint rooms in this case particularly the bedrooms and kitchen result in disproportionately long and thin rooms. In reality however these rooms remain successful once accommodated with furniture, and bedrooms are aided significantly by the spatial relief offered by the additional volume of the open roof void.

8.05.6.3 DETAILED DESIGN

- Diaphragm panels posed the greatest challenge throughout the detailed design, manufacture, and construction phases of the project. External lapped joints were relatively easy to accommodate within the prefabricated panel, however they did generate an added complexity to the panel design and manufacture. The need to provide a continuous sheathing from the wall plate to intermediary beams restricted panel heights to the available board dimensions, in this case 2440 x 1220mm. This resulted in a maximum floor to ceiling height of 2337mm once finished with appropriate laps incorporated. Providing internal overlaps throughout the construction was much harder to achieve.
- The greatest challenge and limitation however came from the use of lateral internal walls to provide diaphragm resistance. Combining the intermediary floor and integrated services with double sided diaphragm panels to the internal walls caused considerable complexity in the detailing and programming of the construction.
- As described in Section 8.04.5.2, the proposed detailing and assembly of intermediary floor joists was not realised on site. This resulted in the

addition of metal straps installed across the intermediary floor zone to provide a diaphragm connection between wall panels. Although at greater cost than the proposed detail, it is likely that this solution would have offered a significantly more efficient prefabricated and constructed detail if proposed initially.

- This process has clearly demonstrated that providing racking resistance to the internal faces of external and internal walls can not be easily accommodated in the design of prefabricated panels. The provision of rack-able sheathing boards to the external face of the external walls is relatively easy to achieve using open panels however it does complicate the manufacturing process.
- The project provided considerable learning points regarding the detailed design of panels, most notably related to the specification of diaphragm panels. However, as panels were often detailed to make use of solid studs, they do not offer a fully resolved conclusion to the design of infill panels.

DIMENSIONAL COORDINATION

- The use of a 600mm grid in plan did little to simplify and standardise component sizes in order to realise economies of scale through repeated components. This is again however largely the result of the need to overlap the frame to provide racking resistance. The decision to fabricate panels to full bay sizes however is also a significant factor. If structural bays had been manufactured as multiples of standard 600mm width panels as proposed, a good level of replication would have been achieved. A minimum of two panel types would have been required for each bay before windows are accommodated; a perimeter panel providing overlap with the column and a centre panel without overlaps.

NATIONAL HOUSE BUILDING COUNCIL

- The project was unfortunately not the correct vehicle to address the concerns of NHBC, due primarily to timescale. In discussion with the technical division of NHBC it would appear possible to resolve bespoke details, specifically the suspended timber floor detail in relationship with external ground levels, however it will require a significant investment of time. It is also evident through discussions with others whom are developing MMC systems, that non compliance with the strict standards of the NHBC is proving to be a common concern. Further work is clearly required, however in this scenario. The replacement of the suspended timber floor with a concrete raft foundation successfully resolved the immediate concern of warranty compliance, albeit at the expense of the sustainability objectives of the Project Team.



CLOCKWISE FROM TOP LEFT

Figure 8.110: The living room.

Figure 8.111: Staircase with feature light.

Figure 8.112: Master bedroom open to the roof volume.

Figure 8.113: Master bedroom with mezzanine void to living room below.

OPPOSITE PAGE

Figure 8.114: Layered roof build up of wood fibre insulation, overlapping the gable end to meet the line of the yet to be installed wall insulation.

Figure 8.115: Rigid Rockwool insulation applied to the north dining room pop out.

Figure 8.116: Cut and fitted around the fixed stainless steel window lining.



ENVIRONMENTAL PERFORMANCE

- The performance requirements of the Passivhaus Standard have tested the system far beyond the standard of current industry practice. The desire to incorporate locally sourced materials, products and labour throughout the project has significantly increased the complexity of this challenge and consequently resulted in a failure to meet the Standard. Typically this was due to locally available products and materials not fulfilling the stringent certification requirements of the Standard.
- The realised construction is proposed to achieve CSH Level 5 on its conversion from visitor centre to occupied home. Primarily this is achieved through a fabric first approach with the following performance characteristics;
 - Wall U-value - 0.11 W/m²K;
 - Floor U-value - 0.07 W/m²K;
 - Roof U-value - 0.10 W/m²K;
 - 0.8 W/m²K triple glazed Welsh sweet chestnut windows;
 - Total energy demand for space heating and cooling <21kWh/m²/yr;
 - Mechanical ventilation with air source heat recovery;
 - Ty Unnos system details are designed to achieve air permeability of 0.25ach at 50 Pa as well as reducing thermal bridging;
 - Lighting: 100% LED or low energy fittings throughout;
 - 4m² Solar hot water array
- In general, the homegrown timber system was reasonably adaptable to the standard details recommended by the Passivhaus Standard, however thermal conductivity was identified as a limiting characteristic. The thermal conductivity of the post and beam frame, despite its insulative infill, significantly reduced the thermal performance of the envelope, specifically at nodes where solid connectors compromised an area of the thermal envelope. The effect of this was reduced by the specification of a substantial external layer of rigid insulation. However the project has illustrated that an evaluation of thermal performance of system components is essential and may require alterations to the design of components in order to meet higher performance standards.

FINISHES

- There have been few conflicts directly related to the detailed design of the homegrown timber components. The application of external insulation boards however generated a number of unique and challenging detailing issues including, the depth and reveal of openings, the fixing of cladding,



CLOCKWISE FROM TOP LEFT

Figure 8.117: The kitchen corner window.
Figure 8.118: Punched openings to the first floor landing and master bedroom.
Figure 8.119: The porch and home office pop out.



OPPOSITE PAGE

Figure 8.120: Ventilation ducts passing through downstairs bathroom, to be accommodated within a dropped ceiling.
Figure 8.121: Ventilation duct turned through 90 degrees to floor level within bathroom wall.
Figure 8.122: Ventilation ducts accommodated within the dropped ceiling void.
Figure 8.123: Stairs will be encased with a solid balustrade wall providing an understairs store. Ducting visible at low level.



and concerns with interstitial condensation within the roof construction. These issues were resolved and constructed efficiently and effectively with the provision of an additional breather membrane and the use of substantial fixings capable of passing through external insulations to fix directly into the primary structure.

- Service distribution within internal walls has generated a conflict with diaphragm panels, however the use of a service void within the airtight envelope has proved to be very successful with the airtightness membrane and primary structural elements remaining unaffected by the positioning and distribution of services. The distribution of ventilation ducts however has been much harder to accommodate due to their size, requiring a false ceiling within the central core of the plan at both ground and first floor, see Figures 8.120 - 8.122. It is likely that alternative plans proposed in the pattern book would be much harder to accommodate this solution.
- The specification of a ground floor bearing slab successfully resolved a large number of concerns related to the use of a suspended homegrown timber floor detail. The provision of a slab also ensured that the predominantly timber building incorporated a source of thermal mass. In conjunction with underfloor heating and locally sourced slate flooring this significantly improved the building's ability to store and radiate heat gained from passive design principles.

8.05.6.4 MANUFACTURE

- The manufacture of components placed a considerable and unique pressure on the supply chain due to the significantly restricted timescale. The lessons learnt from this process have been incredibly valuable. A project of this scale currently requires a minimum six week lead in time for manufacture. However with greater standardisation and experience it may be possible to reduce this, particularly the time required for the production of manufacturing drawings.
- The project revealed a number of sourcing issues of homegrown timber, specifically regarding quality and the availability of stock on a day to day basis.
- A significant percentage of the supplied homegrown softwood was found to be Douglas Fir, which is typically stronger and straighter than Sitka spruce. However Douglas Fir also has a much greater torsional strength which proved much more resistant to the installation of large diameter screws. This has resulted in noticeably slower assembly times and puts greater strain on tools and carpenters
- The quality of the components received on site was generally high with few issues recognised during assembly. The quantity and complexity of



CLOCKWISE FROM TOP LEFT

Figure 8.124: Front entrance and driveway.
Figure 8.125: North and east elevation with dining room popout.
Figure 8.126: South garden elevation



the production information and number of panel types resulted in some discrepancies with the delivered panels, typically due to panels being sheathed to the internal face rather than external, and some panels did require significant adjustment on site.

- Fixings proved to be a considerably confusing factor. The number and cost of fixings is substantial with over 500 screws required for a typical 3m wide wall panel.
- In typical timber frame panel assembly, the edges of OSB sheathing are employed as a guide or template to set out the timber stud frame with accuracy and enable the manufacturer to manipulate a frame to square. With the provision of overlaps to each edge, reliance is placed on the initial squaring of the frame and the accurate positioning and fixing of sheathing boards. This proved to be an inefficient process and, due to the number of alternative arrangements, it was not possible to create an efficient jig to assist the process.
- Tolerances for panel design were discussed at length during the production of information with a tolerance of 5mm ± 2mm to the perimeter and between abutting panels ultimately agreed upon. Frame components were typically realised to a tolerance of ±2mm.
- Kenton advised that due to the decision to manufacture a number of elements using ladder beams, there was minimal material waste resultant from the manufacture of the frame and infill panels. Whilst the project has confirmed that it is possible to make use of homegrown solid section C16 for the assembly of timber frame panels, it has highlighted the need for a connected approach to the use of the material to ensure that the high levels of rejected material associated with this process can be absorbed into the manufacture of other complementary engineered components.

8.05.6.5 CONSTRUCTION / BUILDABILITY

- The construction of the house has followed a remarkable programme. Works related to the construction of the Ty Unnos construction components required approximately 15 days to complete and a further 5 days to infill with insulation. This timeline is perhaps not exceptional when compared with other construction systems, however the total construction time of just 65 days for a high performance construction of this nature does seem outstanding compared to an industry average of 900 man hours for a conventional timber frame construction.² Particularly when associated with a single application of new construction methods. This is a testament to the quality of the contractor involved.

OPPOSITE PAGE

Figure 8.127: Battening and cross battening fixed through wood fibre insulation to the first floor to receive vertical cladding
Figure 8.128: Sweet chestnut vertical half lap cladding.
Figure 8.129: Cladding applied to the south elevation.

2 Homes and Communities Agency, *Designed for Manufacture: Lessens Learnt 2* (London: Homes and Communities Agency, 2010), p. 57.

Component	Description	Initial Costing 18 03 10	Revised Costing 24 03 10	Revised Costing 26 03 10	Anticipated Final Account 04 05 10
Frame	Box Section Frame	£ 19,412.00	£ 19,412.00	£ 19,412.00	£ 18,132.00
	Steel and Timber Connectors	£ 6,200.00	£ 6,200.00	£ 6,200.00	
Floor	Floor Cassettes of Ty Unnos Ladders and OSB/3	£ 7,820.00			
	Ground Floor Joists in 1200mm OSB Cassettes		£ 2,866.00		
	First Floor Joists in 1200mm OSB Cassettes		£ 2,866.00		
	Second Floor Joists in 1200mm OSB Cassettes		£ 1,433.00		
	Floor Joists GF&FF Solid C16 Spruce			£ 1,800.00	
	Joist Hangers			£ 400.00	£ 1,632.00
External Walls	Wall Cassettes of Ty Unnos Ladders and OSB/3	£ 20,740.00	£ 15,221.00	£ 6,838.00	£ 11,632.00
	Studded Panels without OSB			£ 6,838.00	
Roof	Roof Cassettes of Ty Unnos Ladders and OSB/3	£ 5,440.00	£ 5,228.00		£ 3,602.00
	Ladder and OSB Cassettes 1200			£ 5,228.00	
	Total	£ 59,612.00	£ 53,226.00	£ 46,716.00	£ 34,998.00
	Per sqm - 132 sqm	£ 451.61	£ 403.23	£ 353.91	£ 265.14
Options	Partial Assembly of frame offsite	£ 2,000.00			
	Assembly assistance on site (2 weeks - 1 man)	£ 2,250.00			
	Timber Treatment	£ 1,000.00		£ 1,000.00	
	Delivery			£ 500.00	
	Insulate Box beams	£ 500.00	£ 500.00	£ 500.00	
	For Concrete Ground Floor deduct		-£ 5,866.00	-£ 3,000.00	
	Profit and Attendance				£ 3,500.00
On Site Works	Supply and fix 210/270mm x 60mm treated timber sole plate. Fixings to be M16 Threaded bar c/ w nuts and washers set at 1mtr centres and fixed with Hilti Hi Hit injection concrete or equivalent				£ 969.19
	Erect frame and panels on site				£ 9,240.00
	Supply and fix 43 No Galvanised Steel connecting plates to secure frame to sole plate				£ 1,349.00
	Supply and fix 18mm OSB to inside face off all internal walls				£ 2,490.83
	Form 2 No 150mm dia holes to each bay within all external and internal walls to allow Warmcell blown insulation to be injected. Recover holes on completion				£ 300.00
	Form 1 No 50mm holes to external box beams to allow Warmcell blown insulation to be injected. Recover hole on completion				£ 10.00
	Warmcell Blown Insulation to Wall and roof panels				£ 3,756.83
	Warmcell Blown Insulation to box beams				£ 536.55
	Warmcell Blown Insulation to internal walls				£ 500.00
	Rockwool Mineral Fibre Loft insulation packed into box beams on site				£ 500.00
	Total	£ 65,362.00	£ 47,860.00	£ 45,716.00	£ 58,150.40
	Per sqm - 132 sqm	£ 495.17	£ 362.58	£ 346.33	£ 440.53

Table 8.4: Comparison of quotations provided by Kenton Jones Joinery.

- Feedback of particular note provided by the contractor was the increased ease of assembly that the solid connector offered over the threaded rod connector detail as employed in the construction of the ERC.
- Crane hire was only required for 3 days on site during periods of frame and infill panel assembly. Scaffolding however was installed up to roof pitch and remained in place for approximately 8 weeks.

8.05.6.6 REFLECTION

ECONOMIC EVALUATION

- The individual component costs of the Passive House as constructed were;
 - Box Section Frame with Steel and timber connectors

£137 per m²
 - Loose C16 floor joists with joists hangers for 1st and loft floor

£29 per m² of floor area
 - Mixed width infil panels for walls consisting of internal and external OSB/3 sheathing with solid section studs and plates

£48 per m² of wall area
 - 1200mm wide infil panels for roofs consisting of internal and external OSB/3 sheathing with 3 Ty Unnos Type 01 ladder beams

£39 per m² of roof area
- An assessment of the elements directly associated with the Ty Unnos construction components are shown in Table 8.4. The anticipated final account column shows that the manufactured components, as supplied by KJJ, totalled £35,000, approximately £265 per m². This is a significant reduction of 35-40% from the initial costings which included a suspended timber floor construction, Ty Unnos Type 01 ladder beams throughout and a greater degree of prefabrication.
- In order to complete this frame assembly on site a further £23,150 was spent on assembly, sheathing and installation of Warmcell insulation. This gives a total of £58,150, equating to approximately £440 per m². This price does not include foundations and ground floor construction, or internal and external finishes, membranes or services.
- The total cost of the Passive House as provided in the anticipated final account of G Adams was £256,848, approximately £1945 per square metre.

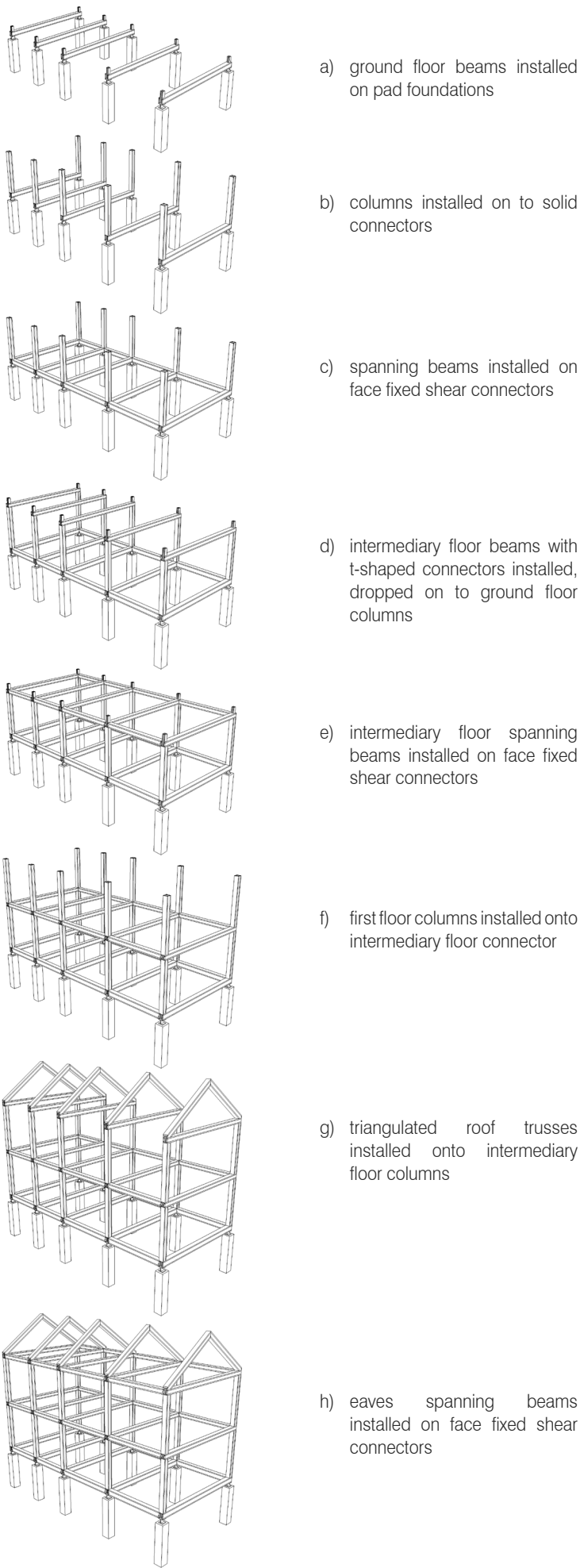


Figure 8.130: Proposed structural arrangement of a post and beam frame

8.06 SUMMARY OF FINDINGS

The four studies have provided a wealth of experience and understanding regarding the opportunities and limitations of homegrown timber components applied in a range of construction scenarios. The following are considered the key summary of these findings;

8.06.1 COMPONENT DESIGN + CERTIFICATION

STRUCTURAL ORGANISATION

Although initially conceived as a combination of portal frames with spanning infill panels, the system has developed into a three dimensional post and beam frame. The portal based system was deemed as appropriate for single storey constructions and was successfully employed for the construction of the Welsh Folklife Pavilion and the ERC. However, this organisation places considerable demand on the design of infill panels and the assembly process, significantly reducing the efficiency and standardisation of panels. Burroughs have advised that the use of a portal frame system is not scalable to multi-storey constructions, therefore spanning box sections were incorporated into the design of the Welsh Passive House at ground, intermediary floor and eaves levels to create a more traditional post and beam frame. In conjunction with racking panels, this arrangement has provided a structural solution for multi-storey constructions with structural spans appropriate to those required for domestic scale structures within the permissible spans of the proposed homegrown timber components.

The proposed design of the structure can be seen in Figure 8.130. Box sections are jointed using solid connectors to form 'portal' type arrangements which are connected by spanning edge beams simply supported on a 'T' shear plate. Due to the capacity of connectors, specifically in resistance to racking, the primary post and beam structure is described by Burroughs as a temporary structural framework. This temporary framework is then infilled with ladder beams and sheathed with OSB in order to realise a permanent structural solution. This conclusion raises great concerns over the efficiency and value of the post and beam structure, which equates to a considerable percentage of the system costs. The Project Team have generally concluded that the primary structure must fulfil a more valuable role to warrant its inclusion.

DIAPHRAGM PANELS

The need for panels to provide racking places considerable restrictions on the detailing of prefabricated infill panel connections and subsequently the standardisation of panels. It also significantly influences the construction process and assembly methods. Whilst OSB applied to the interior and exterior of the frame provides a solution to this essential structural requirement, the need

to ensure continuity from foundations to eaves poses considerable detailing challenges particularly surrounding an intermediary floor structure. The pattern book demonstrates a tendency towards long, thin plan arrangements, due largely to the maximum box beam spans of 4.8 - 5.1m available from standard softwood sections. These two storey organisations tend to be susceptible to high wind loads, further exacerbating the requirements for diaphragm panels.

Diaphragm panels have become a defining element of the detailed design of the system components, and the design flexibility of a proposed system. Many of the challenges observed in the design and construction of the Passive House particularly, require considerable additional work to address and resolve an efficient solution. Accordingly, following the completion of the Passive House, Burroughs were commissioned to perform a study to consider alternative methods for providing bracing. This has been briefly discussed in Section 6.01.2. and will form a key aspect of discussion in Chapter 9.0.

8.06.2 BUILDING DESIGN

DESIGN

As prototypical studies have, in the most part, been non-residential applications, it has not been possible to assess in detail the application of a residential pattern book. In general however the studies have demonstrated a good level of flexibility and adaptability to alternative design scenarios, including form, scale and materials.

It should be noted however that these studies have been ideally tailored to the application of the system. In each case the site is essentially virgin, with generous proportions, making it possible to efficiently overlay the site geometry with a dimensionally determined orthogonal organisation. The efficiency of manufactured components applied to a more determined and restricted site arrangement has not been tested here.

SPACE AND QUALITY

The application of a 600mm dimensional organisation has generally been acceptable and efficient in terms of space standards and Lifetime homes. However the permissible structural spans of ladder beams and the available material sizes of sheathing boards, accepted as 2.44m, do pose some restriction on room types and proportions. The extension of the permissible spans of ladder beams to 3.3 - 3.6m would significantly improve the quality of permissible spaces. Also, the limitation of rooms to a maximum floor to ceiling of less than 2.4m is restrictive. The studies have demonstrated that the addition of a 300mm module would improve the efficiency and flexibility of the dimensional organisation when applied to domestic organisations.

OPENINGS

The applied 600mm dimensional organisation has enabled a good level of flexibility in the design and arrangement of openings. However some concerns remain as the base dimension of 600mm is not ideal for small openings, resulting in a limited glazed area when framed and detailed appropriately. Due to the bespoke detailing scenarios of the prototypical studies, the use of a level threshold detail in combination with a suspended timber floor arrangement, has not been addressed through the studies. This arrangement will raise a number of potential detailing conflicts and will need further consideration.

8.06.3 DETAILED DESIGN

SECONDARY STRUCTURAL + THERMAL ENVELOPE

SIPs provide an efficient and high thermally performing solution for infill panels however they do not fulfil the primary aims of the study as they cannot incorporate natural insulations or homegrown timber. Although a number of alternative solutions combining homegrown timber components with sheathing boards have been trialled through these prototypical studies, the detailing and organisation of infill panels has yet to be fully resolved into an efficient system in terms of performance, standardisation and buildability.

The experience of the infill systems trialled in the studies suggest the need to simplify panel designs and find a method of generating much greater repetition. The primary challenge to overcome is the need for panels to overlap both the primary structure and neighbouring panels. The use of a dimensional grid applied to the spacings between primary structures as suggested by the ‘Tartan’ grid employed for the design of the Welsh Passive House, is paramount to achieving this efficiently.

The prototypical studies have reinforced the findings of the weight assessment performed in Section 7.01.8 to suggest that at a domestic scale, organised on a 600mm grid, individual components are suitable for manual handling. The requirements for large scale lifting equipment is therefore minimal and can in some cases be removed entirely.

The efficiency at which the projects have been realised once the primary structure is assembled generates a reasonable reassurance that a system of prefabricated homegrown timber components could provide an efficient solution to residential scale construction.

WARRANTY AND NATIONAL STANDARDS

The NHBC are essential to the success of the system for general residential application. This became abundantly clear throughout the prototypical studies in discussion with clients and other parties. The use of an Architect’s certificate,

although successfully resolving a single project, does not provide a long term solution for a system. There are a number of significant divergences from accepted standard practice which need to be addressed in discussion with the warranty provider and Building Control. This will require time and financial investment, and would require contributions from both Architects and Structural Engineers.

ENVIRONMENTAL PERFORMANCE

The studies have demonstrated that the proposed system of components are adaptable to a range of performance specifications and is capable of achieving the fabric demands of higher levels of the CSH and the Passivhaus Standard.

The performance of the thermal envelope is currently compromised by the primary structure specifically at junctions. Where a solid section connector is used at nodes, there is a significant increase in thermal conductivity. It is not yet clear what this equates to in reality as formal performance data is not available for this bespoke detail. It is clear however that the scale of this performance compromise needs to be assessed as a priority, and the detailed design of the post and beam frame and connections reviewed accordingly.

8.06.4 MANUFACTURE

During the development of these projects the manufacture of components has developed dramatically. The ERC and Coed Llandegla were developed with the valuable guidance of specialist engineers and fabricators, Cowley Timberwork. Subsequently, the Project Team were able to hand over a significant amount of each project to the specialists and learn some extremely valuable lessons from their experience. Later projects however turned to local members of the industry with significantly less experience in the construction industry. In general this transition has been extremely successful, suggesting that the project has achieved its objective; that is to develop a set of products which can be accommodated within the existing capacity and facilities of Welsh timber enterprises. This is undoubtedly due to the perseverance and ambition of the Project Team and especially Kenton Jones, who has demonstrated a willingness to invest significantly to support the project.

The most challenging aspect of this process, however is the generation of information. During the manufacture of the ERC, much of the production information was generated in house by Cowley Timberwork based on General Arrangement drawings provided by the Architect. With the manufacture of the Passive House and the Welsh Pavilion, most of the production information was generated by the Architect. This is a unique consequence of the structure of the Project Team, and is unlikely to be efficient if applied to a more traditional architectural approach. A system build of this nature is unlikely to realise a wide

market appeal if the responsibility of generating manufacturing information is placed on the Architect or other building consultant. There is a concern that without the addition of in house technical assistance or a much greater standardisation of production information, the manufacturing of a system build will be inefficient to adopt generally.

SUPPLY CHAIN

The timber supply chain has suggested a number of concerns related to the consistent supply and quality of material. Concerns typically relate to the availability of stock at short notice and the inconsistent quality of material, particularly in terms of moisture content and the variation in species delivered as softwood. Distortion remains an issue, however the processes involved in the manufacture of engineered components have enabled waste to be dramatically reduced.

8.06.5 CONSTRUCTION / BUILDABILITY

Each project has demonstrated that the construction processes associated with homegrown timber components can be easily incorporated into practice without specialist training or support. Although many of the methods require a different approach to standard timber frame construction, skills are generally transferable and adaptable.

The assembly of the Welsh Folklife Pavilion has demonstrated that a system of small components such as these could offer an efficient method of construction for low-skilled or experienced individuals such as self builders without significant demand for mechanical lifting equipment.

The bespoke constructions suggest that the proposed system of homegrown timber components could realise a structural envelope in approximately 15 days.

8.06.6 REFLECTION

ECONOMIC PROFILE

Although each building study provided an alternative specification and integrated alternative homegrown timber components, they have provided a surprisingly consistent associated cost profile. Based on an approximation of the performance specification outlined in Chapter 5.0, the cost per square metre has ranged from £440 to £520. This includes primary structure and thermal envelope and in some cases includes the provision of internal finishes.

However the development of the Welsh Passive House has highlighted a concern over the cost of individual homegrown timber components, with existing market alternatives such as JJI joists and solid imported timber joists offering significant savings over engineered homegrown timber components.

OCCUPATION RESPONSE

In all cases the building studies have received considerable, positive feedback from clients, inhabitants, media and the general public. This has included a number of formal recognitions from the architectural, political and timber communities including;

The ERC - Shortlisted for Wood Awards 2010, and the RIBA Awards 2011. Awarded the National Eisteddfod Plaque of Merit July 2011.

The Welsh Passive House - won the InnovaWood European Forest and Timber Network Prize for Innovation and Technology Transfer in 2011

Chapter 9.0

Rural Studio, Tregynon

a whole building prototype construction study

9.01 INTRODUCTION

The final element of research focuses on a direct investigation into the use of homegrown timber components as a method of self build construction for affordable housing. The study has three primary objectives;

- to test and develop construction processes using a system of homegrown timber components for ease and buildable simplicity as a self build rural housing solution,
- to develop low intensity manufacturing processes appropriate to the existing timber processing industries of Wales,
- to refine a system of homegrown timber components as a whole house construction system to meet the performance specification identified in Chapter 5.0.

As a medium to achieve these objectives a full prototype construction study has been completed at the site of Coed Cymru’s head office, the Old Sawmill, Tregynon.

In the following chapter, the findings of this study will be recorded and analysed. The study is set out as an experiment, with a series of studies proposed, and then tested through detailed design, manufacture and construction.

In Chapters 6.0 - 7.0, design led studies have shown that;

- Homegrown timber components can be applied to spans and structural arrangements appropriate to those required for low density, affordable housing.
- A range of house patterns appropriate to rural housing, based on a small scale system of prefabricated construction components, are feasible.
- A good level of manufacturing efficiency can be achieved in the prefabrication of homegrown timber components using semi standardised processes and existing skills and facilities available from high end secondary processors.
- The proposed method of construction can realise fast and efficient onsite construction programmes when delivered by skilled operatives with experience in the construction industry.
- There remains a number of design and construction details that, at this time, must be considered as limiting to the general application of homegrown timber components, these include; compliance with NHBC construction standards, a standardised system of dimensionally coordinated thermal infill panels, the efficient provision of racking resistance, and a resolved multi-direction primary structural connection.

The prototype building has been manufactured and constructed using skills appropriate to the self build context, and the machinery and facilities of a standard prototyping workshop. It is proposed that by employing this restricted ‘apparatus’, in conjunction with a challenging rural site, a scenario is established which is considered a ‘worst case scenario’ for self build construction.

As established in Section 2.09.3, for the purposes of this study, ‘self build’ is considered to be individuals with little or no construction experience, that have a motivation to develop skills and construct their own properties to meet their individual needs for affordable housing. Self build as an ‘industry’ can often involve highly skilled and experienced individuals, however, as demonstrated by the Walter Segal construction method, by establishing a simple system of construction which utilises readily available components and tools, individuals at all levels of construction experience are given the potential to build their own home.

Although considered as a small and temporary unit, the Rural Studio endeavours to provide a complete thermal envelope to meet the higher targets of the Code for Sustainable Homes, and suggests detailing and componentry which can be scaled to full scale house constructions. Component detailing extends to the design of interactions with doors and windows, and the integration of insulation and services, to provide a ‘whole-house’ solution to meet all of the requirements set out in Chapter 5.0 Performance Specification.

Figure 9.1: Methodology of study showing filtering of system opportunities and limitations through application as a whole house construction prototype

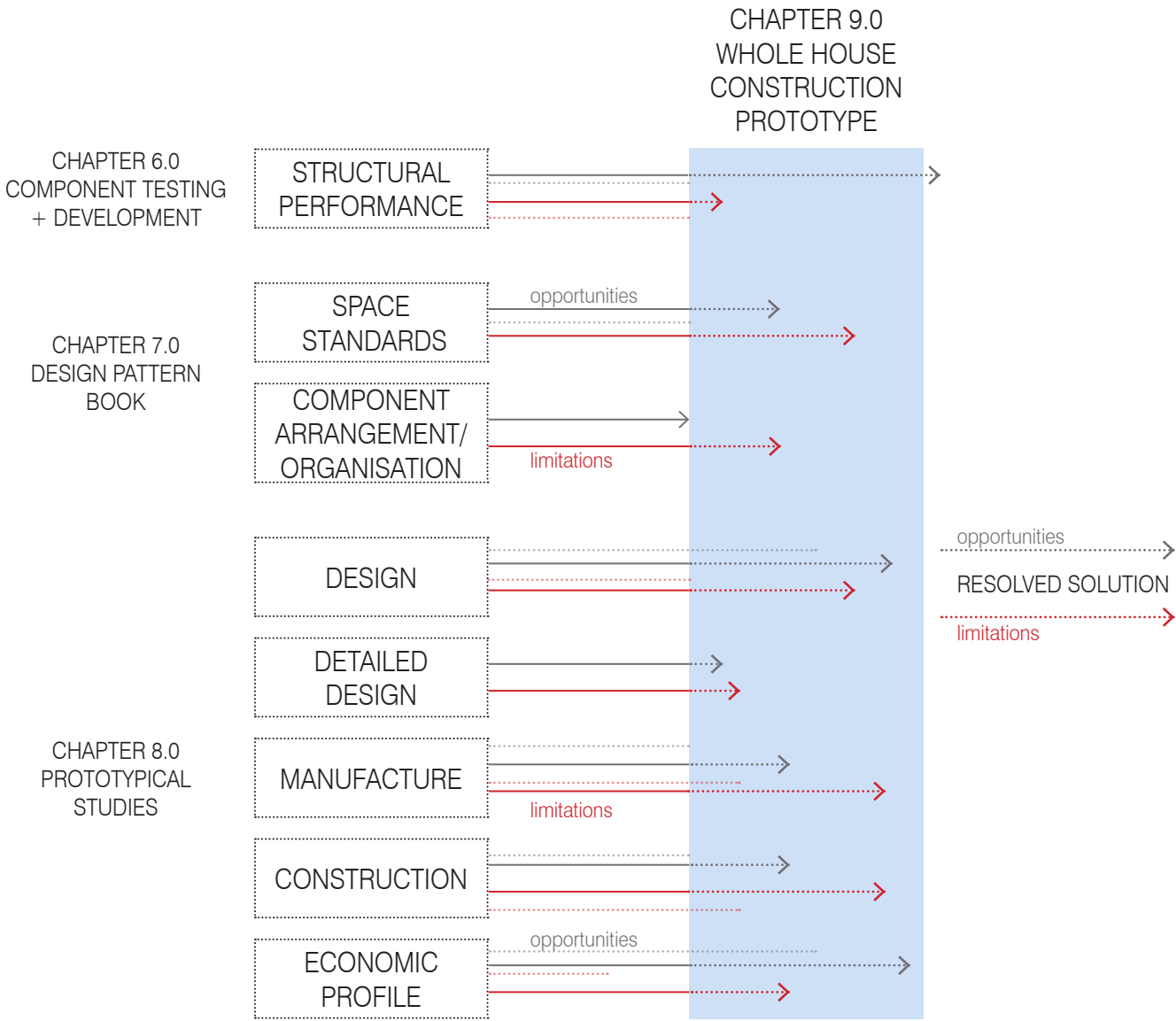


Figure 9.3: General internal arrangement of preliminary design.

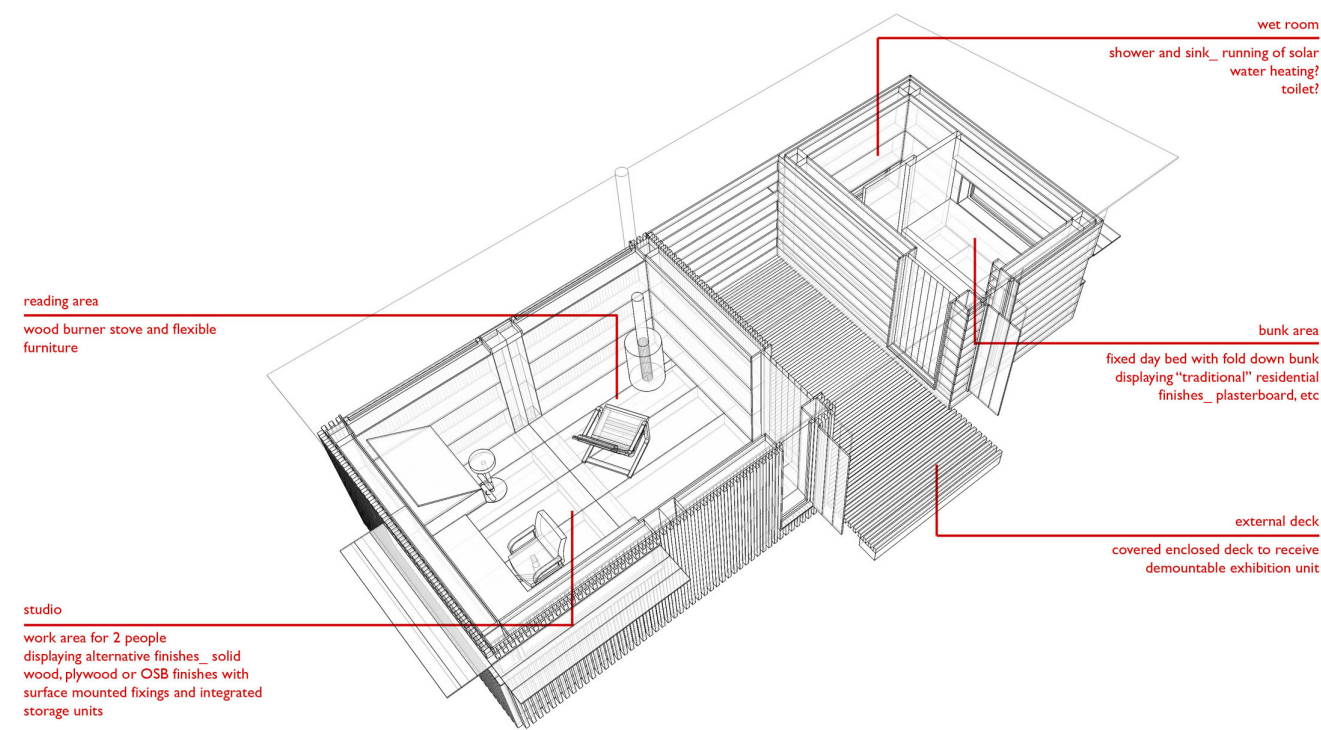


Figure 9.4: South west corner window to the work space.

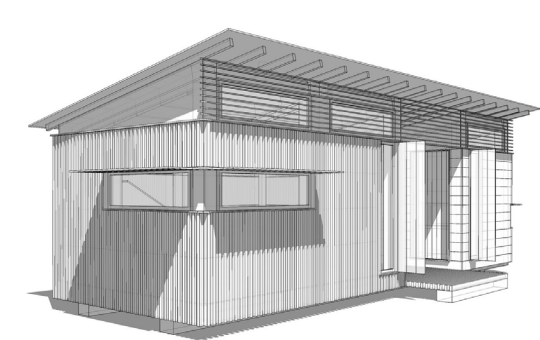
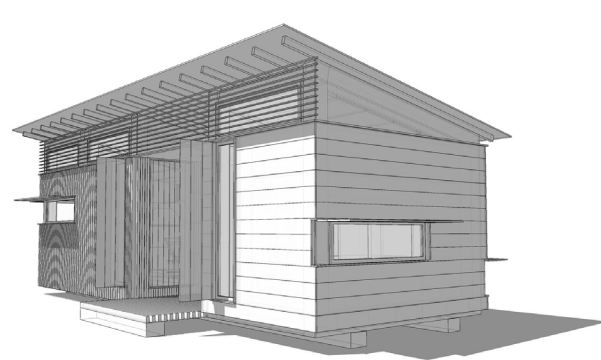


Figure 9.5: South east bunk house.



OPPOSITE PAGE
FROM TOP LEFT

- Figure 9.6: Gregynog Hall.
Source : Ty-penguin
<<http://www.panoramio.com/photo/11268559>>
- Figure 9.7: The development site looking east to the sawmill.
- Figure 9.8: The sawmill and yard from the south west boundary.
- Figure 9.9: The immediate development site in the shade of a sycamore.
- Figure 9.10: The east elevation of the Victorian Sawmill.
- Figure 9.11: Panorama of the Tregynon Old Sawmill site looking north with the Bechan flowing beyond the north boundary of dense mature trees.

9.02 DESIGN DEVELOPMENT

9.02.1 THE SITE

The proposed site is a heavily sloping area laid to grass, tucked under mature trees on the north boundary of the Sawmill. To the south is a sloping tarmac yard used predominantly for the storage of timber to the rear of the Sawmill and car parking to the front. Immediately to the east of the site is a mature sycamore tree. Beyond this to the east is the west elevation of the Sawmill, providing access to a prototype workshop, store and toilet facilities. To the South West is an area of open grass, heavily sloping down to the site, prone to poor drainage. To the West, an area of dense mature mixed trees continues to the boundary of the neighbouring residential property. To the North, the ground drops steeply away, with mature trees giving way to dense undergrowth, down to the bank of the Bechan, a shallow and fast flowing brook that originally powered the Victorian Sawmill.

The Old Sawmill was originally constructed to serve the Gregynog Estate, accessed along the private road to the south of the Sawmill boundary. The Gregynog Estate was gifted to the University of Wales in 1963 and now provides conference and study facilities for the University. Since 1993 the Sawmill has been the home to Coed Cymru providing office and meeting space alongside a prototyping workshop.

9.02.2 PRELIMINARY DESIGN

In 2008 an initial design proposed a small unit that could offer a satellite workspace for the DRUw and WSA, and provide Coed Cymru with a demountable exhibition unit. The single storey building, constructed of three structurally independent bays connected by an oversailing lightweight roof across an external entrance deck, was designed to allow each bay to be disassembled independently and moved to a variety of exhibition events such as the Royal Welsh Show.

A sum of funding was kindly provided by the Countryside Council for Wales and a successful application made to the Gregynog Estate for permission to construct the unit as a temporary building on the Old Sawmill site.



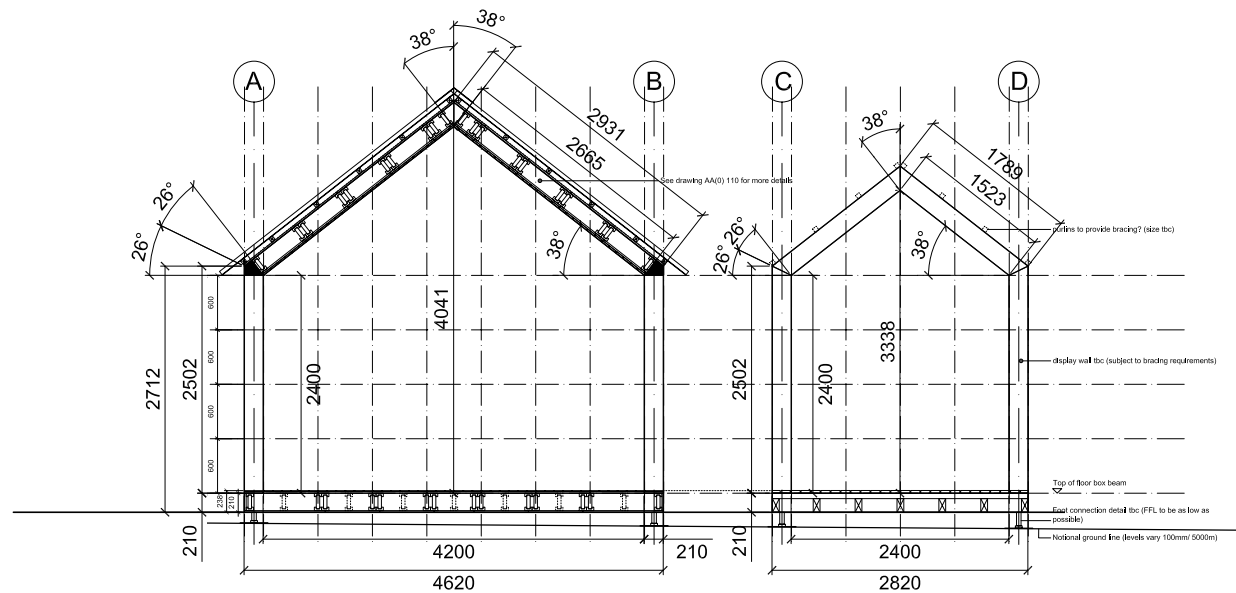


Figure 9.12: Manufacturing diagram of the original Welsh Pavilion proposals with surplus frame arrangement to the right hand side.



Figure 9.13: An example of the traditional Welsh croglofft worker's cottage.

Source : http://www.rhiw.com/hanes_02/adeiladau/bwlchgarreg/bwlchgarreg.htm

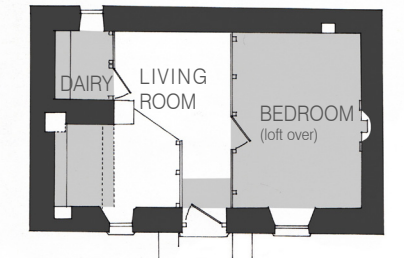
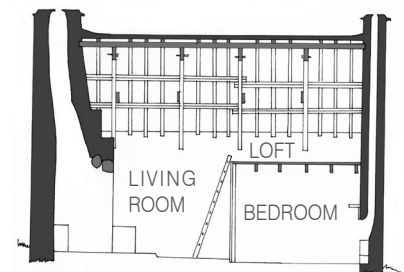


Figure 9.14: Llain-wen isaf, Llanychaer. Ground floor plan and long section.

Source : Iorwerth C.Peate, *The Welsh House*, 3rd Edn (Burnham On Sea: Llanerch Press, 2004) pp. 90 - 92.

9.02.3 RESOLVED DESIGN

The design was significantly revised following the completion of the Welsh Pavilion, due to the availability of a prefabricated box section frame which became surplus to requirements. The available components, originally intended as an external terrace to the pavilion, included 4 pitched 210 x 210mm Sitka Spruce box section portal frames with an internal face to face span of 2.4m and a pitch angle of 38°. See Figure 9.12

The proposed design draws on the precedent of the 18th century rural workers houses known as *croglofft* cottages, as described by Iorwerth Peate in *The Welsh House*;

*As you enter through the door, the kitchen is on your right: a small room with no ceiling between the floor and the roof. On the right of the door as you enter is a wooden partition, three feet wide and six feet high, to keep out the cold. On the left as you go in there is a wooden partition running up to the roof with two doors in it, one vertically above the other. Through the lower door you enter the bedroom: this has a wooden ceiling which serves as a floor to the attic above. To get to the attic bedroom you pull down a ladder which normally sits on the attic floor.*¹

The three bay pitched roof Rural Studio is entered in the centre of the south facing elevation into a flexible living space separating, to the west, a formal working environment and to the east, a serviced kitchenette and WC tucked under the low mezzanine of a loft space, providing a sleeping or storage deck. A central wood burner supplies heat to the naturally insulated building. A composting toilet, array of photovoltaic and solar panels, and rainwater collectors ensure the studio is entirely autonomous making it ideal for temporary satellite rural work spaces.

To the interior, the height and verticality of the long thin building is accentuated by vertically orientated painted tongue and groove boards, whilst to the exterior, cedar shingles will weather to silver, and provide a durable cladding to the north and south long elevations, extending from ridge to ground. Openings frame views of the sawmill grounds and brook, offering light to the main functional surfaces.

The design is an intentionally simple proposal, deemed appropriate in form and materiality to the agricultural and industrial vernacular. Design rules proposed in Section 7.04 have been applied to the arrangement throughout, including determining the positioning and size of openings.

Please refer to Appendix C1 for a full set of design and construction drawings including 3 dimensional graphical representations of the building.

¹ Iorwerth C.Peate, *The Welsh House*, 3rd Edn (Burnham On Sea: Llanerch Press, 2004) p. 96.



Figure 9.15: 3 dimensional long section of the studio.

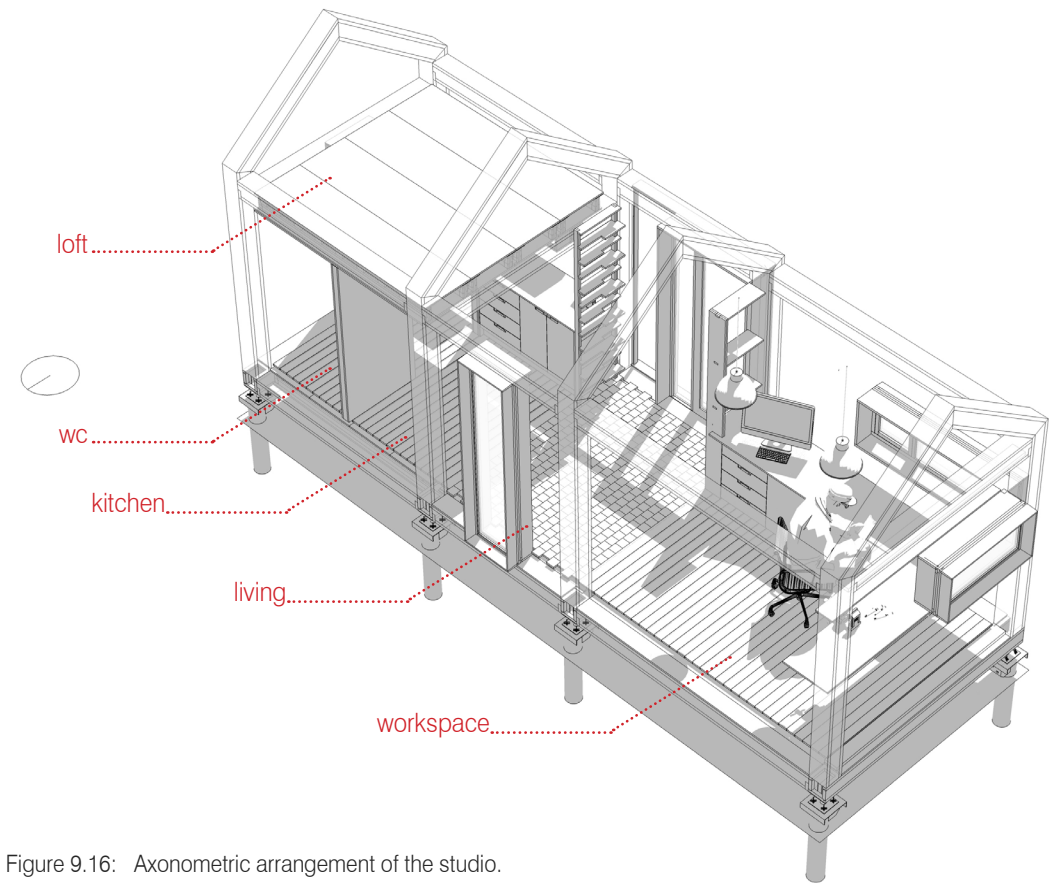
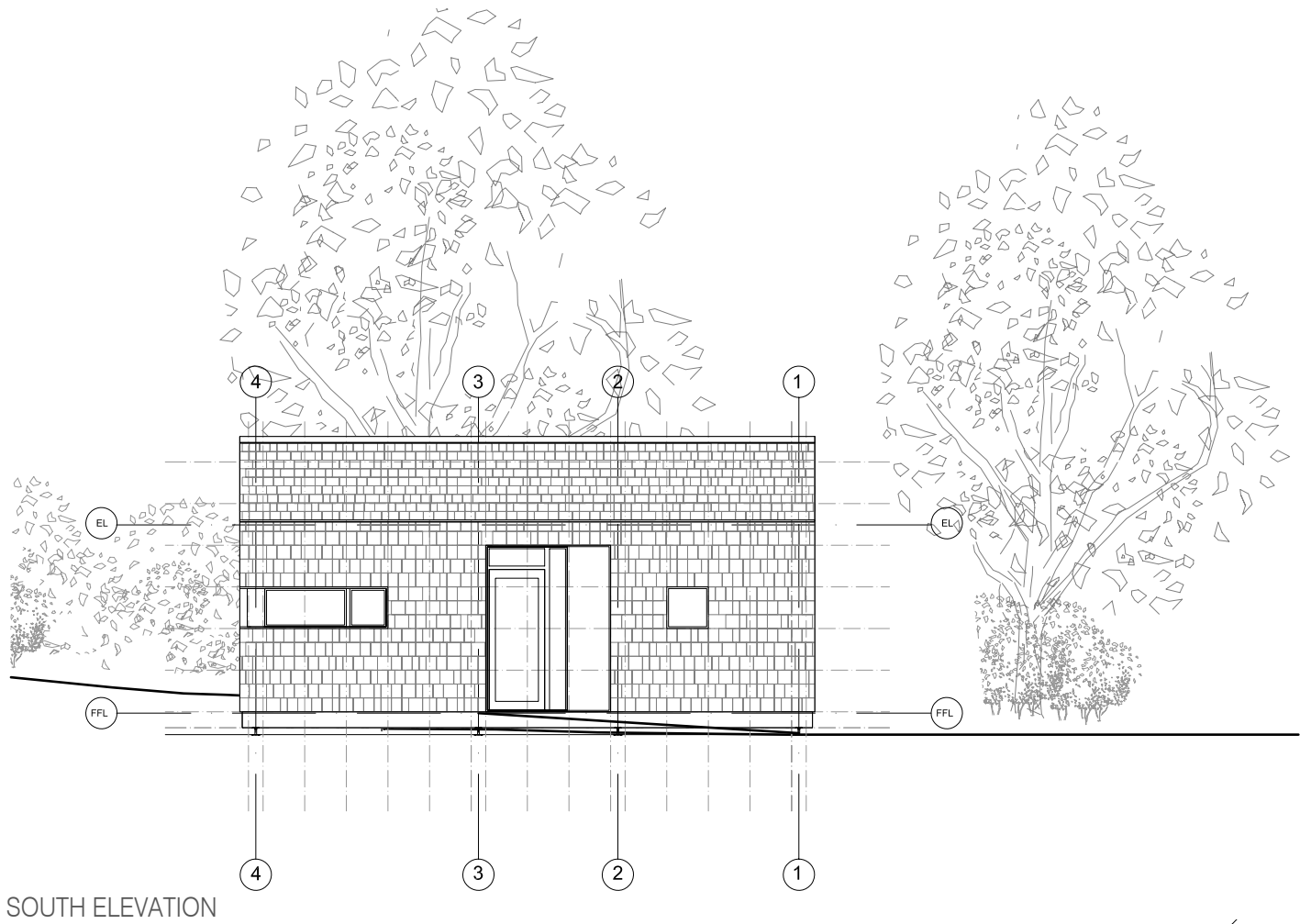
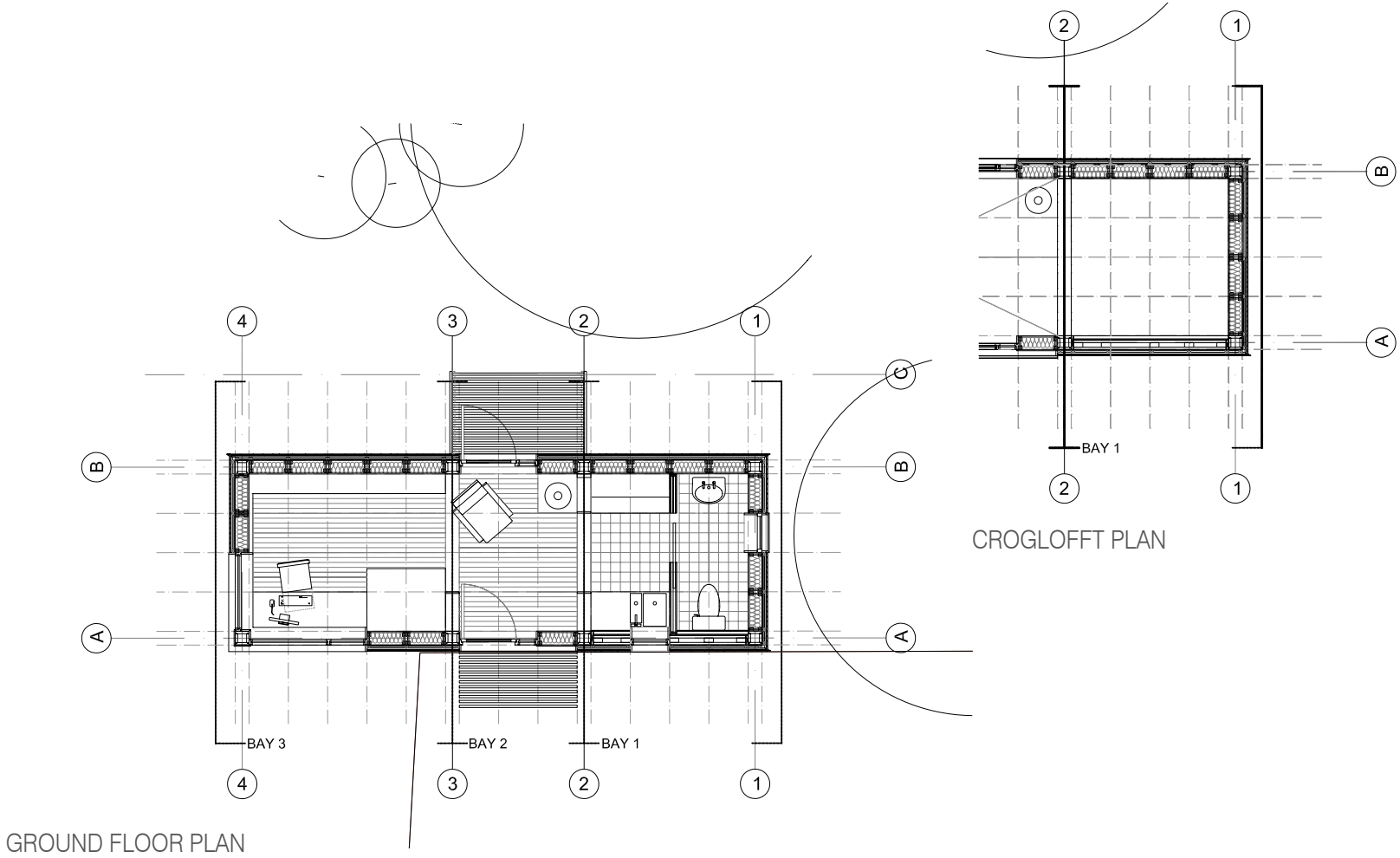


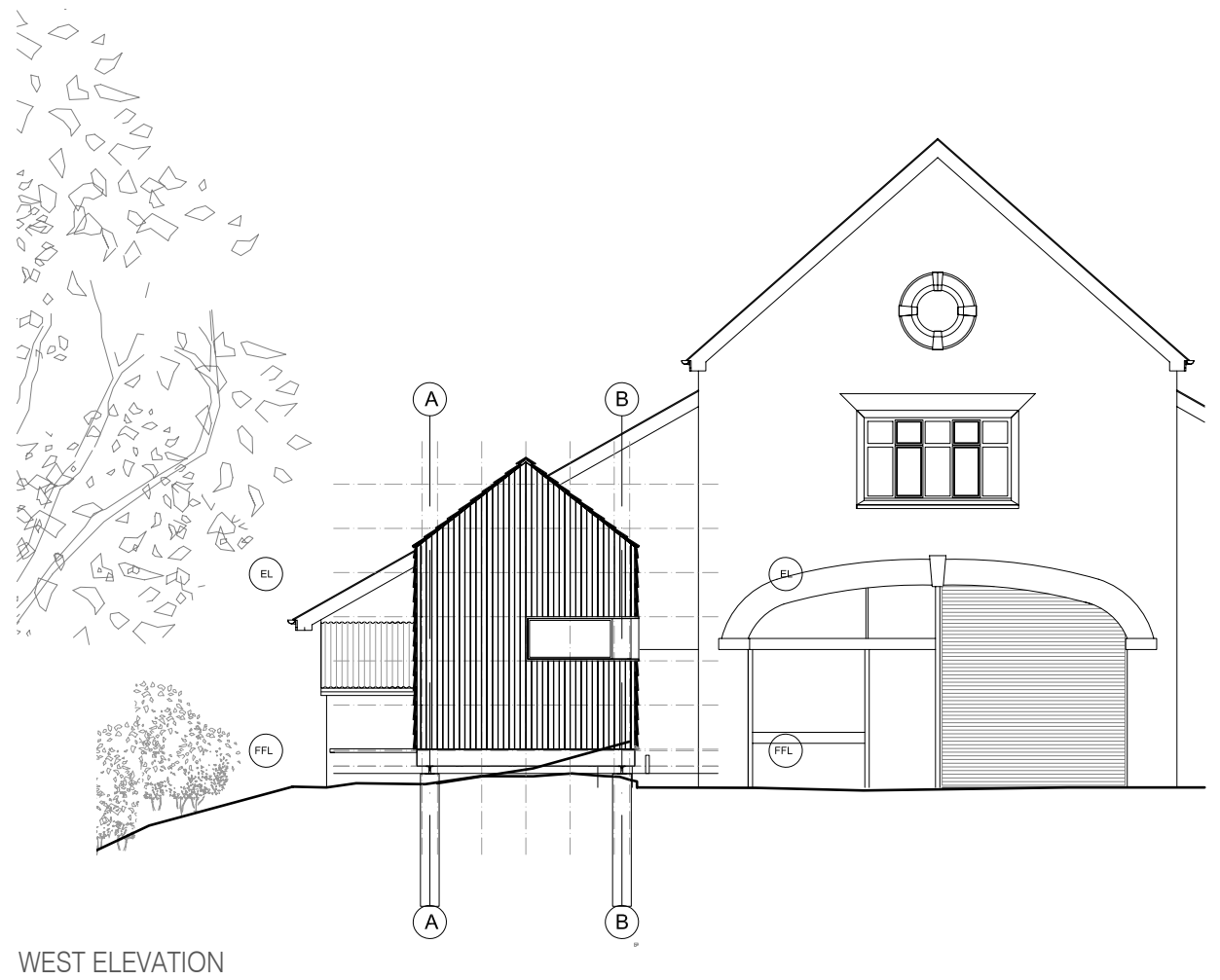
Figure 9.16: Axonometric arrangement of the studio.



SOUTH ELEVATION

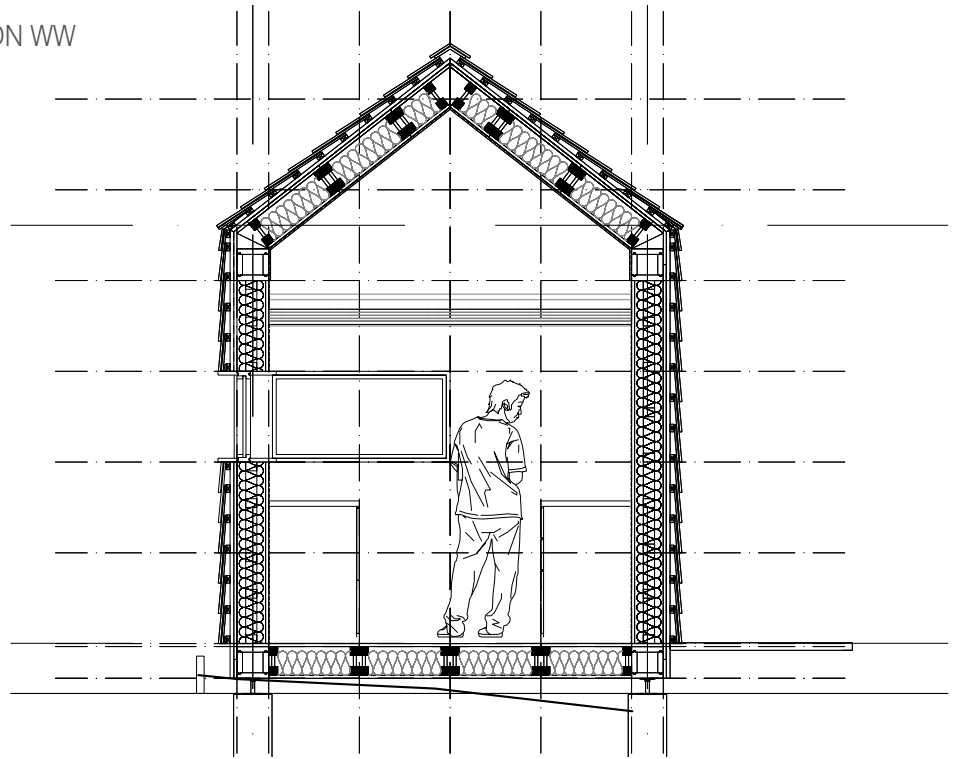


GROUND FLOOR PLAN

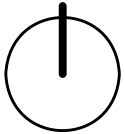


WEST ELEVATION

SECTION WW



TREGYNON RURAL STUDIO COED CYMRU
THE OLD SAWMILL TREGYNON NEWTOWN SY163PL
P 01: PLANNING DRAWINGS
SCALE 1:200 @ A3 12 SEPTEMBER 2010
INNOVATIVE TIMBER HOUSING FOR RURAL WALES



9.03 METHODOLOGY

Chapters 6.0 - 8.0 have enabled the assessment of a broad number of learning objectives as identified in the development framework. This includes a general understanding of the economic, structural, design and performance specification currently feasible using homegrown timber components.

However the nature of each building study, specifically the associated programme, and testing and certification processes have tended to result in homegrown components being applied individually for the delivery of a specific, and often bespoke design challenge, outside the context of a whole house construction solution. This has resulted in a comprehensive understanding of individual homegrown construction components and the opportunities and limitations currently associated with their manufacture and application in construction scenarios.

In order to fully resolve these findings in the specific context of an innovative solution to affordable housing for rural Wales, the rural studio is approached from the ground up as a detailed construction study, to assess, test and resolve as far as feasibly possible, the manufacture and assembly of homegrown timber components as a whole house construction solution. Although clearly on a smaller scale than house construction, the studio is designed to incorporate as many detailed design scenarios as possible in order to provide a scalable reflection of whole house construction requirements.

The study is broken down into five construction elements;

- 01. Sub structure
- 02. Primary Structure
- 03. Secondary Structure + Thermal Envelope
- 04. Openings
- 05. Finishes + Services

The final study is focused primarily on the manufacture and buildability of a system of components. This will however require the close interrogation of the proposed detailed design of homegrown timber components and specifically focus on their combination into a system of thermally useful infill panels.

A series of studies have therefore been designed for each construction element, in order to interrogate the findings of the preceding chapters. Considered as opportunities and limitations to the proposed system when applied to affordable housing, studies are identified for each of the construction elements. Some of these studies are specifically proposed to consider the detailed design of components, and some specifically target construction and manufacturing processes. However in most cases, studies will consider the mutual effect on all



Chart 9.1: Construction programme of the Tregynon Rural Studio

of these factors, in addition to cost and performance.

The arrangement of the primary structure naturally breaks the studio into 3 bays, and each bay into floor, wall and roof panels see figure 9.17. This arrangement is therefore employed as a matrix, with each bay used as an individual test scenario. A number of alternative approaches to each construction element is therefore compared in terms of efficiency of manufacturing and buildability and fitness for purpose.

The primary box section frame is in the most part to be supplied finished by Kenton Jones Joinery however all other items of the construction have been sourced, processed and assembled by myself with the support of Coed Cymru, friends and family. The project should therefore provide a comprehensive first hand experience of the supply chain and the nature of manufacturing and assembling these components.

1. Bay 1 Floor
2. Bay 2 Floor
3. Bay 3 Floor
4. Bay 1 South Wall
5. Bay 2 South Wall
6. Bay 3 South Wall
7. Bay 1 South Roof
8. Bay 2 South Roof
9. Bay 3 South Roof
10. Bay 1 East Wall
11. Bay 3 West Wall
12. Bay 1 East Gable
13. Bay 3 West Gable
14. Bay 1 North Wall
15. Bay 2 North Wall
16. Bay 3 North Wall
17. Bay 1 North Roof
18. Bay 2 North Roof
19. Bay 3 North Roof

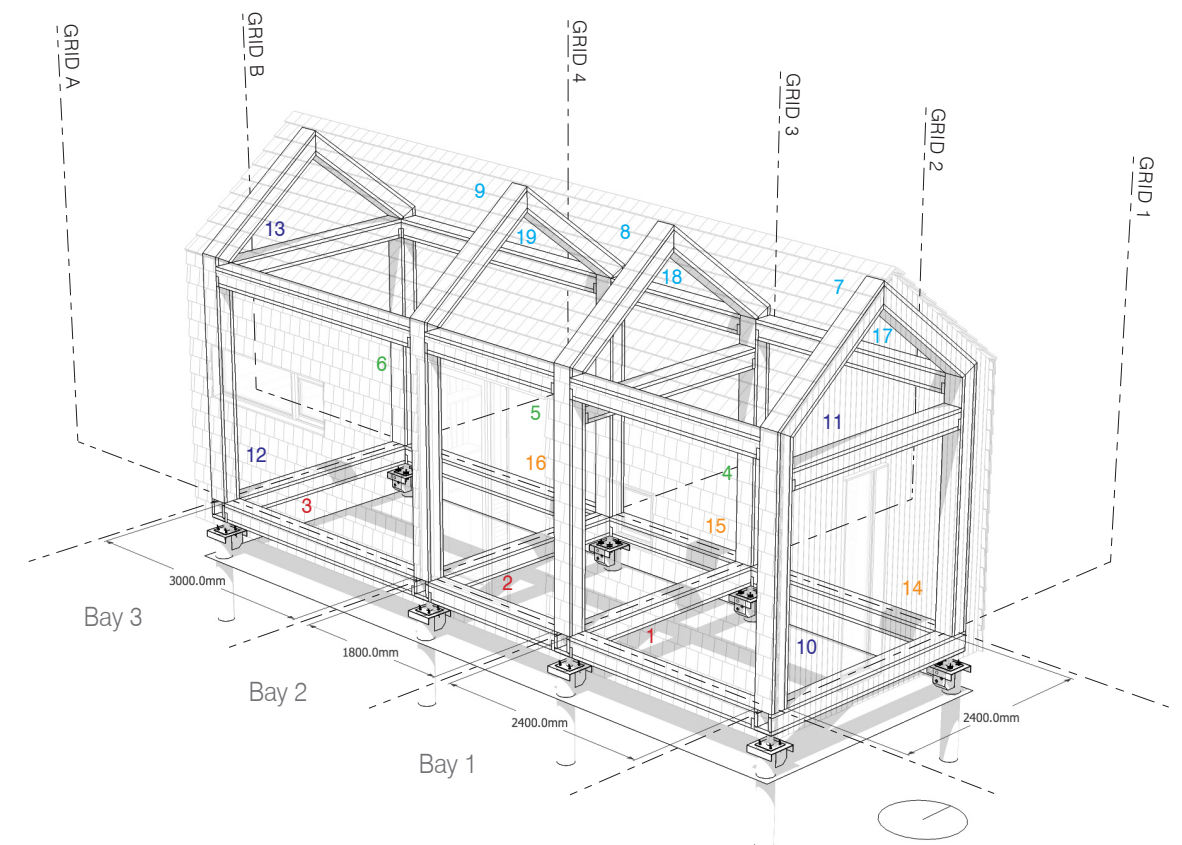


Figure 9.17: Structural arrangement of the proposed studio.

9.04 STUDIES

9.04.1 SUBSTRUCTURE

STUDY 1.1

The system has the potential to place low demands on its foundations with options such as piles, pads and strip foundations being feasible, however the interface with the primary timber structure is critical and may place additional constraints on substructure detailing.

What substructure options are compatible with the proposed components and ensure a minimal disturbance of potentially sensitive and challenging rural sites?

STUDY 1.2

In order to achieve full certification as an affordable housing system, current standards require structural timber elements to be positioned a minimum of 150mm above the existing ground level to ensure protection from moisture. This is in conflict with national requirements for disabled access.

How is a level threshold detail achieved whilst ensuring that the primary timber structure is protected to meet construction standards?

9.04.2 PRIMARY STRUCTURE

STUDY 2.1

The combination of a 3 dimensional frame and a limited working platform due to point load footings poses a potentially challenging scenario for the accurate setting out of the primary structural components.

What is the most efficient method of setting out to ensure accuracy and reasonable tolerance for the assembly of the primary structure?

STUDY 2.2

A system build offers the opportunity to reduce health and safety risks associated with working at height by displacing construction tasks to safe working conditions. However this frequently results in increased demands for mechanical lifting equipment due to the scale and weight of components. Components have been considered for their individual weights however the assembly process is critical to ensure that the demands on mechanical assistance and safety scaffolding are appropriate to the often limited and challenging sites of rural Wales.

What is the most efficient assembly process to ensure that working at height is limited and demands on mechanical lifting equipment and scaffolding can be minimised?

STUDY 2.3

The Ty Unnos system, including the Elements Europe Ty Unnos Modular is based on the original assembly concept of a portalised frame with additional elements spanning between frames. The designed, tested and certified solution for junctions in this frame type have been questioned by a number of parties for varying reasons including;

- the thermal efficiency of a solid connector, even in solid timber, raises concerns of cold bridging at node points, particularly in high energy performance buildings
- the efficiency of prefabricating junctions,
- the limited load capacity of the existing structural joints, particularly in regard to racking,
- the assembly sequence of the primary structure.

What alternative solutions could be considered to provide an efficient, flexible and high capacity multi-direction structural junction?

9.04.3 SECONDARY STRUCTURE + THERMAL ENVELOPE

STUDY 3.1

What is the most efficient assembly process for infill panels, including levels of off site prefabrication, to ensure that working at height is limited and demands on mechanical lifting equipment and scaffolding can be minimised?

STUDY 3.2

Building studies and prototypes have considered a number of detailing options for prefabricated, standardised panels. A dimensional grid of 600mm has been assessed and applied to the design of panels and a number of geometries have been proposed. The geometries have so far failed to fully resolve a homegrown timber solution which delivers an efficient geometry for fabrication and standardisation whilst enabling design flexibility and an efficient construction method.

The prototype construction will therefore primarily provide an opportunity for the testing and development of alternative panel geometries in order to deliver a standardised and prefabricated innovative whole house system of homegrown timber construction components.

How can methods of prefabrication be standardised or mechanised to improve manufacturing efficiency in terms of cost, labour and quality?

What is the most efficient geometry of primary structure for the standardisation of infill panels, and what is the most efficient method of integrating racking resistance?

What approach should be taken to standardising roof pitches in order to promote the rationalisation of infill panels throughout the construction whilst enabling a good level of design flexibility?

STUDY 3.3

Proprietary fixings such as joist hangers and brackets are used in great numbers by the construction industry and specifically the timber frame industry. They can offer considerable time and cost savings, provide predetermined structural performance characteristics and have installation practices that are well known by the industry. It has been suggested that proprietary fixings could offer significant efficiency savings if integrated with structural components.

Can homegrown timber components be combined with proprietary structural fixings to provide efficient solutions for junctions in a prefabricated component system?

STUDY 3.4

Prototypical studies have demonstrated the systems' capacity to adapt to a range of thermal performance specifications and insulation types. These observations suggest that Warmcell offers an efficient and appropriate insulation to meet the objectives of this study.

What is the thermal performance of the proposed basic arrangement of construction components?

What are the effects of the thermal specification on the construction process and is there potential for the integration of insulation into prefabricated components?

9.04.4 OPENINGS

STUDY 4.1

Considered as a whole house system, it is proposed that components such as windows and doors will be fully integrated and coordinated with system components, perhaps in the form of a prefabricated cassette. These components will need to ensure high levels of airtightness and maintain structural integrity within the opening whilst considering the life cycle of the building and the removal and replacement of windows.

Can a prefabricated unit be employed to provide an interface between off the shelf windows and a dimensionally coordinated infill panel system?

How can standard window detailing be employed to ensure flexibility in window types and manufacturers, and ensure replacement windows can be fitted?

STUDY 4.2

In order to meet Design Quality Requirements, DDA and Lifetime homes, there are tight restrictions on entrance door thresholds. To ensure a level threshold between interior and exterior surfaces the threshold detail needs to be carefully considered to achieve flexibility for internal finishes and door types, and to allow the potential for services to be located within the floor construction.

Can a prefabricated unit be employed to provide a level external door threshold and ensure flexibility for internal floor finishes?

9.04.5 FINISHES + SERVICES

STUDY 5.1

A key element of prefabrication is the integration of services. There is precedent for services to be fully integrated into prefabricated panels offsite or for the prefabricated panel to be detailed to receive services when installed on site. The detailing of options place varied demands on manufacture and construction and a careful assessment of these demands need to be made in order to establish the appropriate level of prefabrication.

What is the most efficient and appropriate method of integrating services into prefabricated panels?

9.04.6 PROJECT EVALUATION

STUDY 6.1

A key benefit of MMC systems is the ability to reduce onsite construction times. The study will enable a close assessment of labour requirements in order to identify inefficient processes.

How long does it take to build domestic scale structures using homegrown timber components?

What are the minimum labour requirements to ensure a safe and efficient construction process?

STUDY 6.2

Prototypical studies have provided a general overview of the costs associated with building using homegrown timber components. As material sourcing, manufacturing and construction will be performed within this study, it should be possible to develop an intensive profile of individual component costs when manufactured in relatively small numbers.

What does it cost to manufacture and build using homegrown timber components and what options are there for reducing costs?

9.05 DETAILED DESIGN

9.05.1 DETAILED DESIGN : SUBSTRUCTURE

A suspended timber floor has been a permanent feature of the proposed construction system throughout the study, however it potentially generates some conflicts between;

- NHBC Standards and Disabled Access
- Thermal Mass and Embodied Energy

With the construction of the Ebbw Vale Classroom the issue of ground level in relation to structural timbers was overcome through the design of a retaining drainage channel around the perimeter of the building, effectively shifting the 'ground' level away from structural timbers and providing a suitable level of ventilation to the void below the suspended timber floor construction. Disabled access is achieved sufficiently by bridging this channel wherever access is required. Whilst suitable in this instance the option is severely limited in practice. When applied to multiple housing units for example, increased densities and constrained sites will place much greater restriction on the ratio of land to floor areas.

The challenge of a restricted development site was encountered with the design of the Ebbw Vale Welsh Passive House. In this scenario, in order to meet NHBC Standards a ground bearing concrete slab was employed in place of a suspended timber floor. The alternative option to lift the suspended timber floor 150mm above ground level and provide a 7.5m ramped access to the finished floor height of 420mm above ground was not possible on the site. In this scenario the provision of a concrete slab also provides significantly valuable thermal mass, an essential element of passive design principles and a common limitation of timber constructions.

However the desire to complete a ground floor construction using homegrown timber components remains. This is for a number of reasons;

- The provision of a concrete slab requires the introduction of a number of additional mechanical and skill requirements that are not associated with the timber system. Specifically it is likely to introduce wet trades to the construction program which require a curing period of between 14 and 28 days.
- The embodied energy of a suspended timber floor, constructed using a homegrown timber box section structure and the ladder beams, with a timber based sheathing panel and infill of recycled newspaper insulation would equate to an embodied energy of approximately 430 MJ and 26.5 KgCO₂ per m² of floor area. The equivalent ground bearing slab

constructed of a 150mm concrete slab with 75mm rigid insulation would equate to an embodied energy of approximately 630MJ and 65 KgCO₂ per m². This is a very approximate study however the figures suggest a saving of 30% and 60% respectively in the embodied energy and CO₂ required to provide the alternative floor constructions.

- If coordinated with the manufacturing systems and construction processes employed for walls and roofs, the provision of a timber floor will encourage further economies of scale.

Initially it was proposed that the Tregynon Studio could provide an opportunity to consider a number of alternative footing types, employing alternative approaches for each structural bay. In addition it was proposed that the west elevation, where existing ground levels are at their highest, would offer an ideal opportunity to consider the detailing of a footing and retaining structure which could resolve and test the combination of a level threshold and perimeter details with an appropriately ventilated suspended timber floor. However this required the inclusion of insitu concrete footings, which due to time, budget and planning restrictions, could not be suitably accommodated within this study.

In order to address Study 1.1, a paper study was employed to consider the following alternative footing types in terms of cost, machinery requirements, and fixing / tolerance requirements for the connection with primary structure;

- Helical/ threaded screw piles
- Steel/concrete hybrid driven pile
- Timber Piles
- Concrete Pads/Piles
- Concrete Trench Footings

The details of this study can be found on pages 12-13 of Appendix C2 Design Diary.

REFLECTION

A study of the alternative pile systems suggest that a point load foundation system could be highly appropriate in conjunction with the structural arrangement of the proposed system. Despite the experiences of the prototypical studies during which challenging contexts rendered these systems unsuitable, the variety of available point foundation types should be capable of providing solutions for most sites and geological conditions. Pile foundations offer a strong environmental case, including the ability to entirely remove and return the site to a ‘natural’ condition. All of the pile types considered will offer a significantly lower demand on heavy plant however in some cases, for example helical piles, specialist plant and skills are likely to be required. This study in combination with the prototypical

studies has shown that a single foundation solution is unlikely to be applicable to all development sites however the post and beam frame arrangement should enable the use of sensitive foundation types such as timber, steel and concrete piles. To enable a flexible approach to foundation design and specification, the system should include the design of a ‘universal’ foundation connection which can combine with homegrown timber components to provide connection to all types of foundation.

BELOW GROUND STRUCTURAL TIMBERS

As has been discussed previously a key priority to any structural solution for housing is its ability to meet the requirements established by the NHBC Standards for the provision of NHBC Buildmark warranties. Figure 9.18 sets out the acceptable arrangement of structural timber in relation to ground, as shown in Chapter 6.2 of the NHBC Standards. In order to provide disabled access to the house, the primary structure, with a minimum depth of 210mm is likely to be below ground level, and in direct conflict with the NHBC Standards. During the detailed design of the Welsh Passive House, discussions with the NHBC concluded that detailing structural timber below ground can not be considered acceptable within the standards, however in collaboration with the NHBC it may be possible to develop a bespoke detail which may be considered acceptable in warranty terms, in certain cases. Following discussions with Craig White of Modcel, it is clear that this limitation is a recurring issue with a number of innovative construction systems. There appears to be four main design challenges in order to provide a potential solution to this conflict;

- Provide an appropriate supply to a ventilated void of at least 150mm below structural timbers. This is suggested to be not less than 1500mm² per linear metre of wall or 500mm² per m² of floor area provided by openings on at least two opposite sides.²
- Provide suitable drainage and protection from flooding of the below ground ventilation void if below the surrounding ground levels.
- Provide a structurally sufficient retention of the surrounding external ground level if above the level of the ventilation void.
- Provide a secure barrier to insects and rodents, as well as a safe and secure ground condition to the perimeter of the building whilst maintaining the required ventilation level and ensuring that the building can be placed in close proximity to the boundary.

These factors have not yet been successfully addressed to meet the requirements of NHBC however there appears to be two approaches to a potential solution;

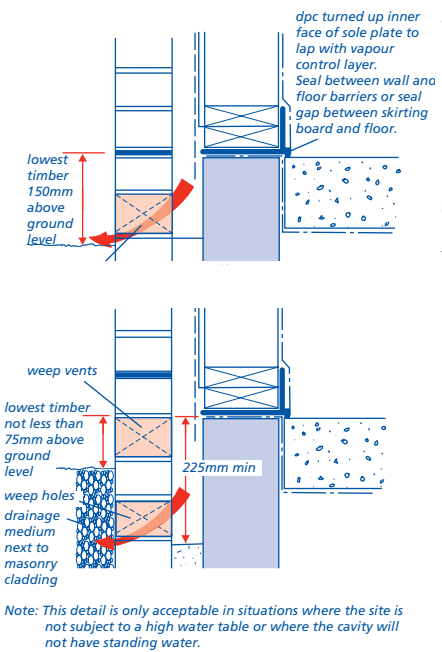
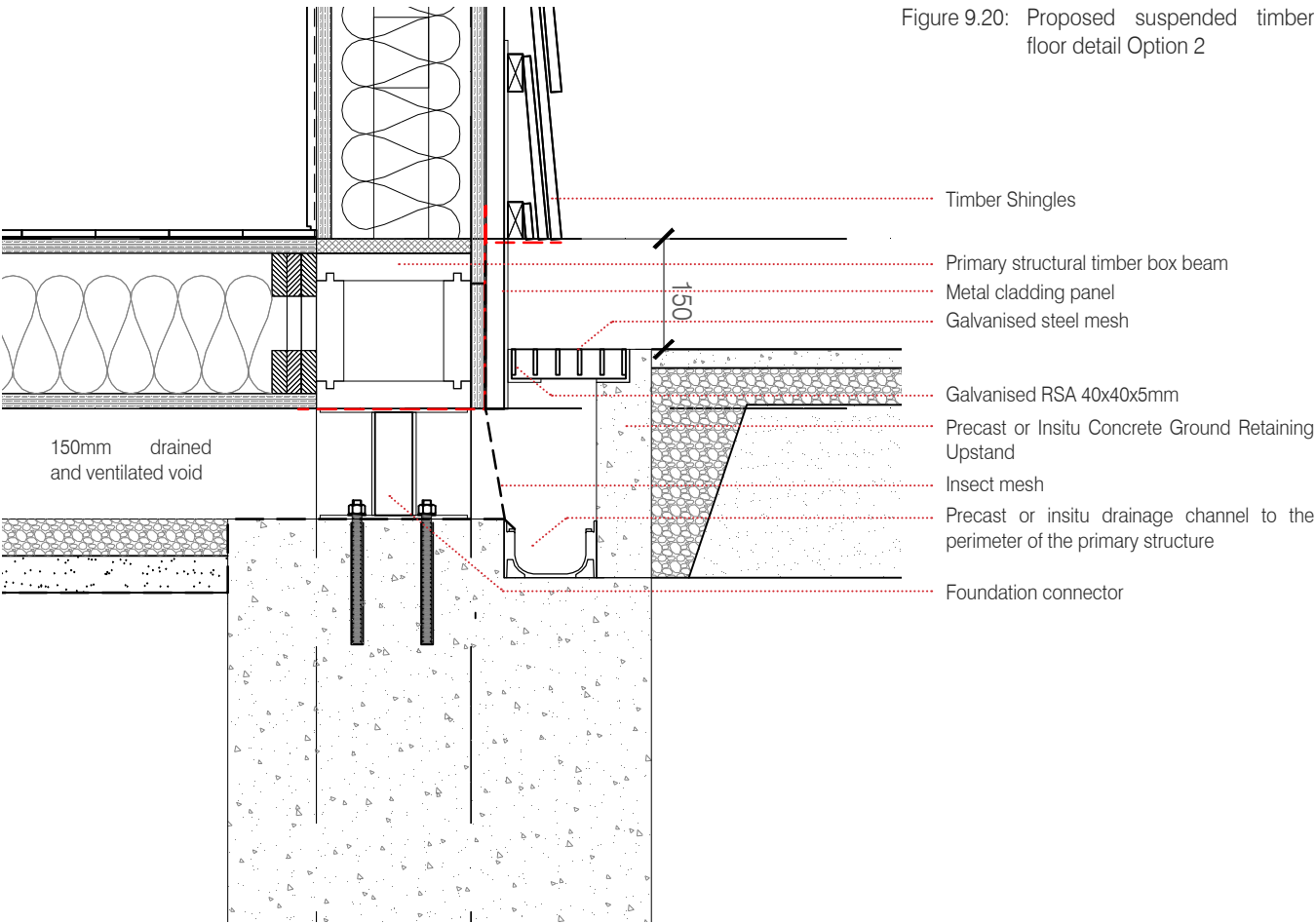
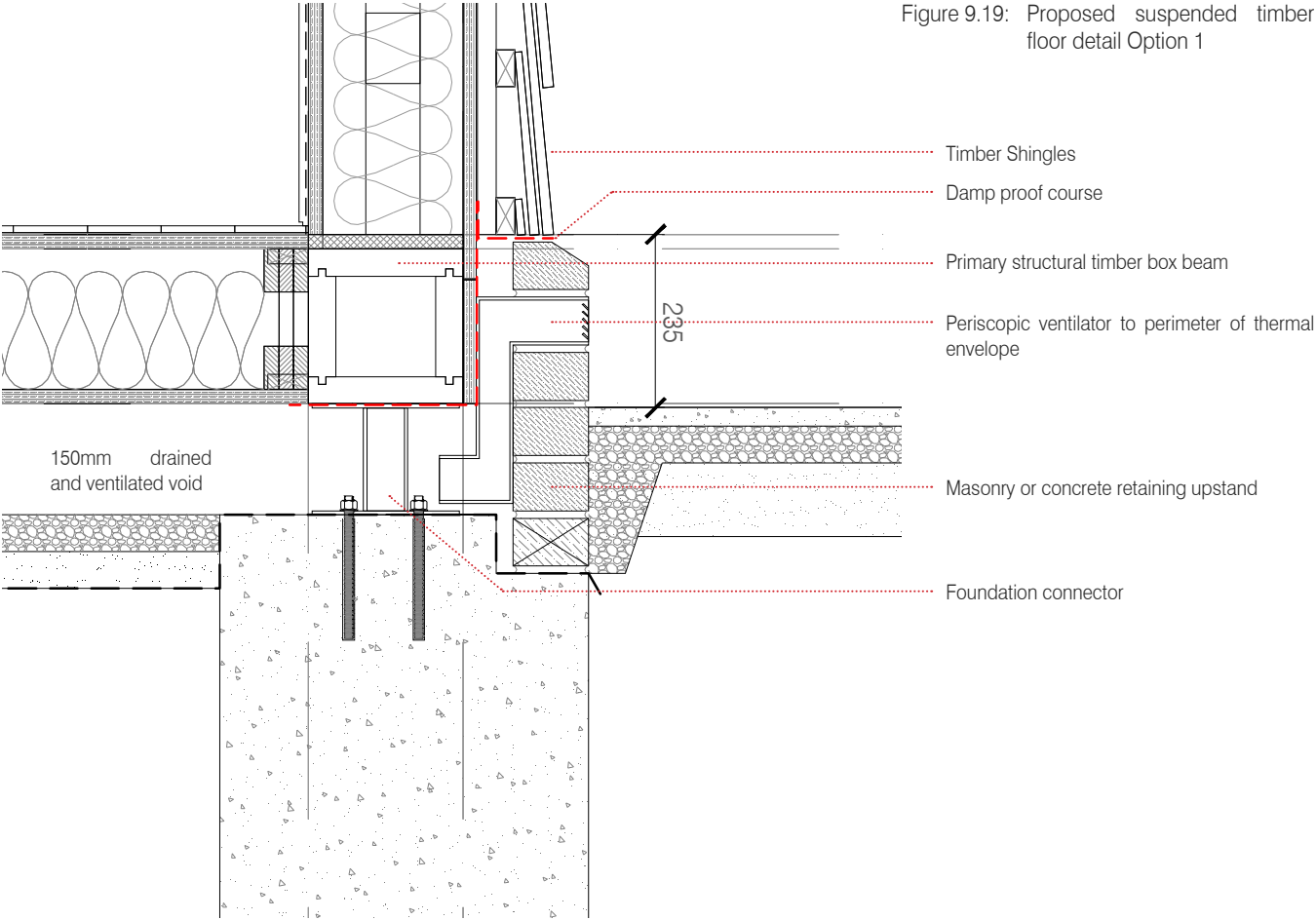


Figure 9.18: Permitted detailing of structural timbers in proximity to external ground levels.

Source : NHBC, ‘Chapter 6.2 External Timber Frame Walls’, *NHBC Standards 2010* (Milton Keynes: NHBC, 2010) p.2.

2 NHBC, ‘Chapter 5.2 Suspended Ground Floors’, *NHBC Standards 2010* (Milton Keynes: NHBC, 2010) p.2.



- Create a dry and tanked basement type construction with retaining masonry walls to damp proof course, with ventilation provided in the manner of periscopic masonry ventilators. See Figure 9.19.
- Provide a continuous open ventilation void to the perimeter of the building protected by a grillage type mesh with integral drainage channels and overflow. See Figure 9.20.

Theoretically both options provide a method of resolving the primary concern of the proximity of structural timber to ground moisture, however there are a number of limitations associated with each:

- Option 1 will affect the physical appearance of external finishes with masonry construction required to a minimum of 150mm above ground level, potentially protruding beyond the line of lighter weight claddings above. In addition it is likely that a retaining wall detail will require a continuous footing to the perimeter of the building.
- Option 2 will have a minimal visual effect on the finished building as ventilation grills can be provided in the ground plane however risk of flooding of the below ground void remains a considerable concern.

The research project has not provided a sufficient opportunity to resolve this detail with the NHBC however it would appear that there are a number of approaches that could be explored in the future.

RESOLVED SUBSTRUCTURE DESIGN

As funds were limited and a primary concern for the substructure design was the ability to return the site to its 'natural' condition, two temporary foundation types were worked up for the studio;

- Concrete paving slab foundations
- Driven timber pile footings

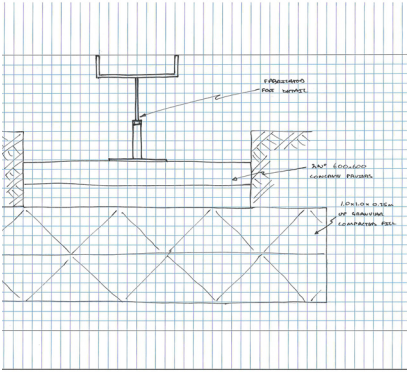


Figure 9.21: Concrete paving slab foundation detail proposed by Burroughs.

Although there was very limited guidance available for the design of timber piles, in discussion with David Jenkins and local farmers, I was advised of the common system of driving 8" preservative treated gateposts into the ground for agricultural gateposts. With the knowledge that the building is to be temporary, with a likely lifespan of much less than 5 years, and would undergo limited loading during this time, the building was considered a highly appropriate opportunity to test the performance of preservative treated homegrown timber in a low risk scenario.

It was therefore proposed that a test pile would be driven at gridline 1A and if considered to be structurally robust, this would be implemented across the remaining nodes. DWG AA(0)102 Pile Cap, shows the design of the timber pile. The design includes a timber pile cap notched into the pile to provide an increased bearing area.

A post base type connector with 200x200mm top and base plates separated by a short length of circular hollow section is anchor bolted into prepared footings and bolted to the underside of the plate using the threaded rod extensions of the primary frame connections.

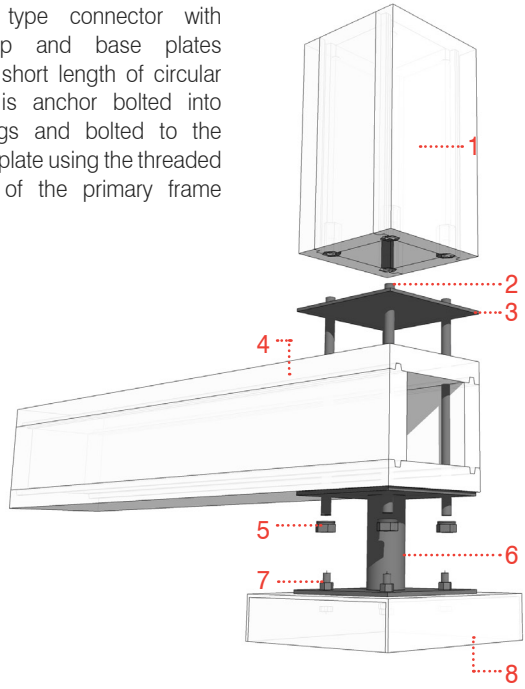


Figure 9.22: Type 01 - Threaded Rod Connector

- 01. 210x210mm Sitka Spruce Column
- 02. M16 Resin bonded threaded rods into box column
- 03. 8mm Steel spreader plate
- 04. 210x210mm Sitka Spruce Floor Beam
- 05. M16 nuts
- 06. Simpson Strong Tie post base/ 'I' section
- 07. Resin Anchor bolts into;
- 08. Footing

A post base type connector with 200x200mm top and base plates separated by a short length of circular hollow section is anchor bolted into prepared footings and coach bolted to the underside of the ground floor beam, passing through the bottom flange directly into the timber / hybrid connector.

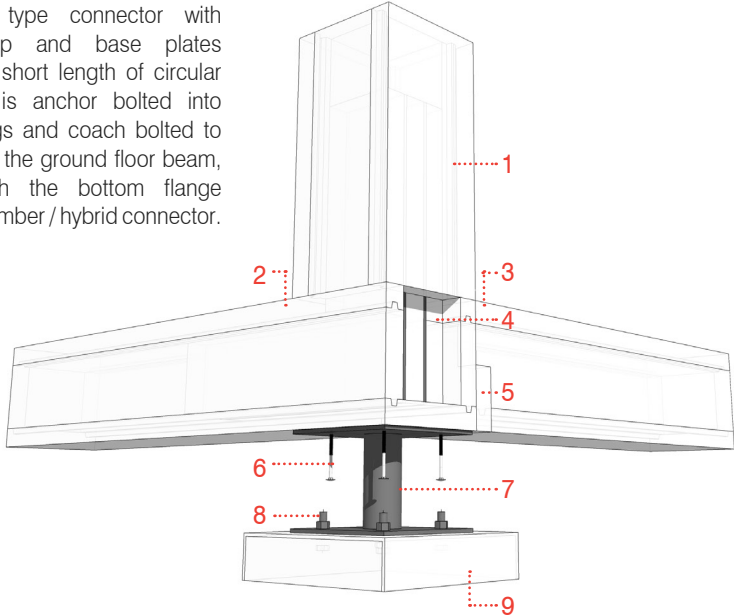


Figure 9.23: Type 02 - Post Base Connector

- 01. 210x210mm Sitka Spruce Column
- 02. 210x210mm Sitka Spruce Floor Beam
- 03. 210x210mm Sitka Spruce Edge Beam
- 04. Timber and steel 2 dimensional solid connector
- 05. Sitka Spruce shear connector
- 06. Coach bolt
- 07. Simpson Strong Tie post base/ 'I' section
- 08. Resin Anchor bolts into;
- 09. Footing

Similar in geometry to Type 01 and 02, the top plate of the connector is adjusted to include vertical 'wings' which enable a bolted connection into the webs of the primary structure. An alternative design for shear plates is required to fit over the exposed connector and bolt heads.

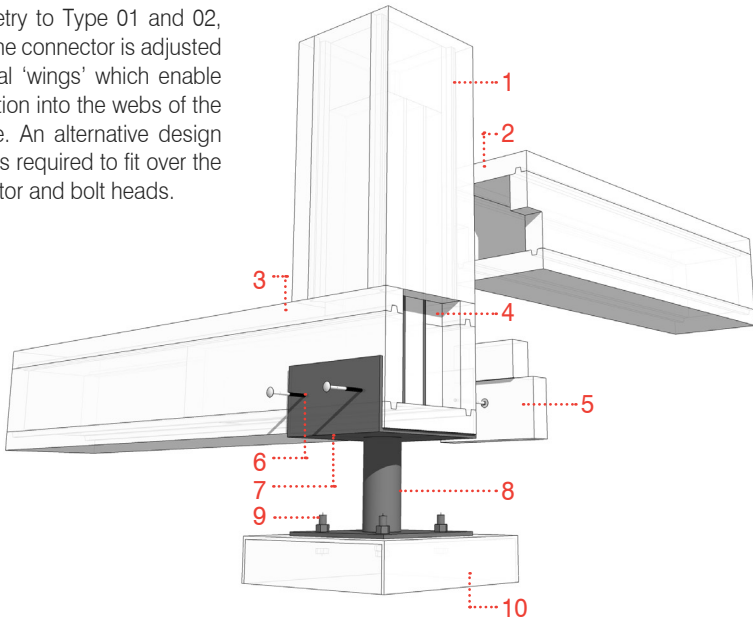


Figure 9.24: Type 03 - Winged Base Connector

- 01. 210x210mm Sitka Spruce Column
- 02. 210x210mm Sitka Spruce Edge Beam
- 03. 210x210mm Sitka Spruce Floor Beam
- 04. Timber and steel 2 dimensional solid connector
- 05. Sitka Spruce shear connector notched to allow steel wings
- 06. Coach bolt
- 07. Extended 'wings' on upper plate of;
- 08. Simpson Strong Tie post base/ 'I' section
- 09. Resin Anchor bolts into;
- 10. Footing



Figure 9.26: Hot rolled steel I section foundation footing as used for the Ebbw Vale Resource Centre including steel bearing plate between beam and column.

9.05.2 DETAILED DESIGN : FOUNDATION CONNECTION

In the prototypical studies to date, a short length of 'I' Section hot rolled steel has been employed as a separator between the top of structural foundation and the bottom of the primary box section. Whilst successfully used in the ERC combined with a threaded rod connector it was generally reflected that the I section is not ideal for a universal application. Specifically the solid steel web requires access on two sides of the floor beam in order to install fixings. Once floor panels are in place however access can only be made to those available from the perimeter of the building. A suitable connection is therefore required to provide;

- Separation between top of foundation and bottom of structure of a minimum 150mm,
- A suitable geometry to enable access to install fixings,
- A reasonable tolerance to account for discrepancies in fixing points,
- And be developed in conjunction with primary structural junctions and diaphragm panels to enable a suitable structural connection between primary structure and footings.

There are a number of potential solutions on the market including Elevated Post Bases available from Simpson Strong Tie, see figure 9.25. These would seem to be structurally appropriate, however the geometry of the top plate is smaller than necessary and is likely to result in localised crushing of the primary structure. Based on this principle however a number of options were proposed for bespoke connectors. These can be seen in Figures 9.22 - 9.29.

REFLECTION

The design and assessment of these alternative solutions has focused on a number of key factors;

- accuracy and flexibility of the connection to onsite setting out,
- ease of installation, specifically access to fixings,
- structural capacity,
- and flexibility for alternative types of foundations

Types 01 - 05 demonstrate a similar approach to the design of the connector. Based on the post base connector available from Simpson Strong Tie, the connectors have a top and bottom bearing plate separated by a circular hollow

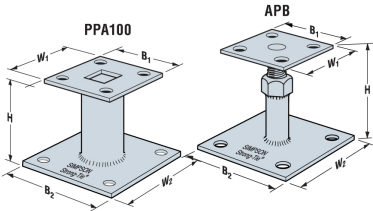
Figure 9.25: Standard post base connectors available from Simpson Strong Tie.
Source Simpson Strong Tie.

ELEVATED POST BASES TO SUIT VARIOUS SIZES AND ELEVATION REQUIREMENTS.

MATERIAL: Plate: 4mm mild steel.

FINISH: Galvanised.

Model No.	Dimensions (mm)					Bolts (Total)		Characteristic Capacity (kN) C24
	W1	B1	W2	B2	H	Qty	Dia.	
PPA100	100	100	130	130	100	8	11	55.9
APB100/150	100	100	130	130	100-150	8	11	45.0



A similar iteration combines the foundation connector with a steel plate extending up the outer face of the column with all fixings made into the base of column, including direct connection with diaphragm sheathing panels.

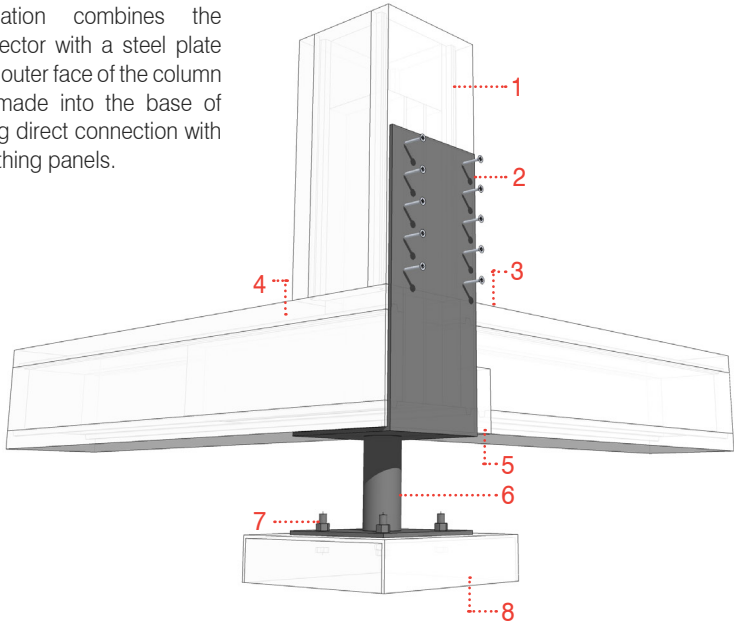


Figure 9.27: Type 04 - Column Plate

- 01. 210x210mm Sitka Spruce Column
- 02. Screw fixings through steel plate upstand
- 03. 210x210mm Sitka Spruce Edge Beam
- 04. 210x210mm Sitka Spruce Floor Beam
- 05. Sitka Spruce shear connector
- 06. Simpson Strong Tie post base/ 'I' section
- 07. Resin Anchor bolts into;
- 08. Footing

Similar in form to Type 03, the vertical 'wings' are reduced in height to extend just the height of the bottom flange to allow connections into the side faces. This is proposed in combination with a multi direction primary frame connector which includes additional arms to catch spanning edge beams in place of shear connectors.

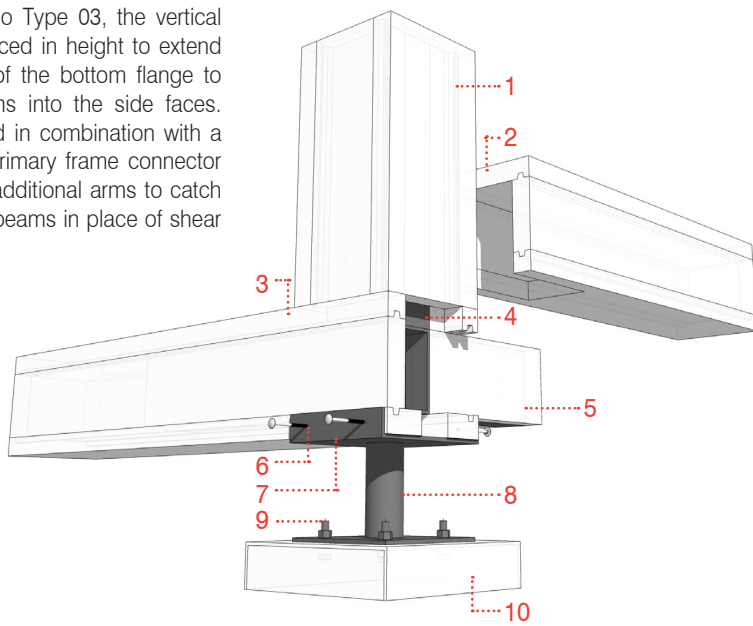


Figure 9.28: Type 05 - Winged Base Connector With Multi Direction Connector

- 01. 210X210mm Sitka Spruce Column
- 02. 210x210mm Sitka Spruce Edge Beam
- 03. 210x210mm Sitka Spruce Floor Beam
- 04. Multi directional connector of hollow box steel
- 05. Hardwood cheeks bolted to steel connector
- 06. Coach bolt
- 07. Reduced height 'wings' on upper plate of
- 08. Simpson Strong Tie post base/ 'I' section
- 09. Resin Anchor bolts into
- 10. Footing

This option combines the primary structural connector and foundation connector into one unit. Constructed of hollow rectangular steel with timber hardwood cheeks, the vertical arm of the connector is extended beyond the bottom flange of the floor beam and welded to a bearing plate which is anchor bolted into the foundations. All fixings are driven directly through the primary structure into the cheeks of the connector.

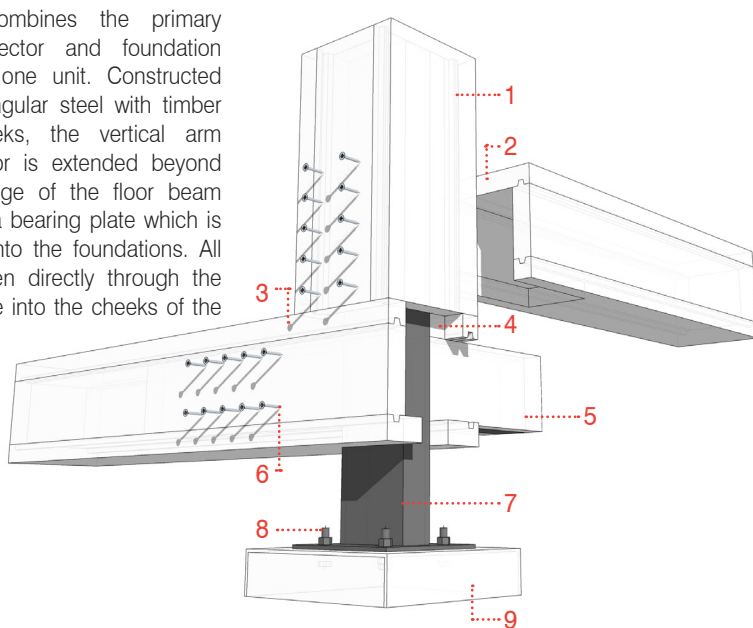


Figure 9.29: Type 06- Multi Directional Connector With Extended Column

- 01. 210X210mm Sitka Spruce Column
- 02. 210x210mm Sitka Spruce Edge Beam
- 03. 210x210mm Sitka Spruce Floor Beam
- 04. Multi directional connector of hollow box steel
- 05. Hardwood cheeks to steel connector
- 06. Screws
- 07. Connector extended to form 150mm upstand
- 08. Resin Anchor bolts into
- 09. Footing



Figure 9.30: Prototype of foundation connector fabricated out of softwood and OSB to trial the geometry of fixings.

section. The bottom flange will sit atop the foundations and enable direct connection in the form of anchor bolts or cast in fixings, whilst the primary ground floor beam will bear directly onto the top flange. The approaches however demonstrate alternative fixing arrangements. Type 01 and 02 require access to be gained to the underside of the primary structure. Actions such as drilling and installing fixings may be restricted due to the limited access afforded on site therefore the assembly process will require careful sequencing to ensure an ease and accuracy of fixing.

Winged connectors designed into Type 03, 04 and 05 offer a potentially easier assembly process, with fixing points accessed from above and to the sides of the primary structure. In addition Type 04, if connected through the external sheathing into the primary structure, may offer a structural solution with capacity for transferring racking loads directly into the foundations. However in all cases, the installation of the connector and the primary structure will require an increased level of accuracy as there is very limited dimensional tolerance permitted when the connector is folded to the geometry of the box section.

Type 06 offers a distinctly alternative solution by combining foundation connector, primary frame connector and shear plate connector in to a single component. This solution potentially offers a greater opportunity for accuracy in the junction and, if detailed correctly could offer the simplest and most intuitive assembly process. All of the proposed frame connections make use of the hollow box section, this requires components to be able to slide, either laterally onto the arms of the connector or perpendicularly via a removed face of the box section. There are therefore two options for a combined connector, either the connector is fixed in place to the foundations with a high level of accuracy with all box sections slotted down onto the network of nodes or the connector is free to be manoeuvred and assembled with the primary structure prior to being fixed into the foundations. Both options will require careful detailing and testing to ensure that the assembly processes are efficient and allow a realistic level of tolerance on site. This option will be considered further in section 9.04.3.

PROTOTYPE

An initial prototype of a system specific post base connector was manufactured out of timber in order to test the geometry in conjunction with the required fixings. In order to provide a greater level of tolerance between the position of the primary structure and the installed timber pile, a bearing plate was included underneath the post connector, spreading any off-centre load across the full width of the proposed timber pile cap. The use of a circular hollow section provided a good level of access to fixings at all sides of the connector however in order to allow access for a socket wrench, fixings were limited to a length of approximately 60mm.

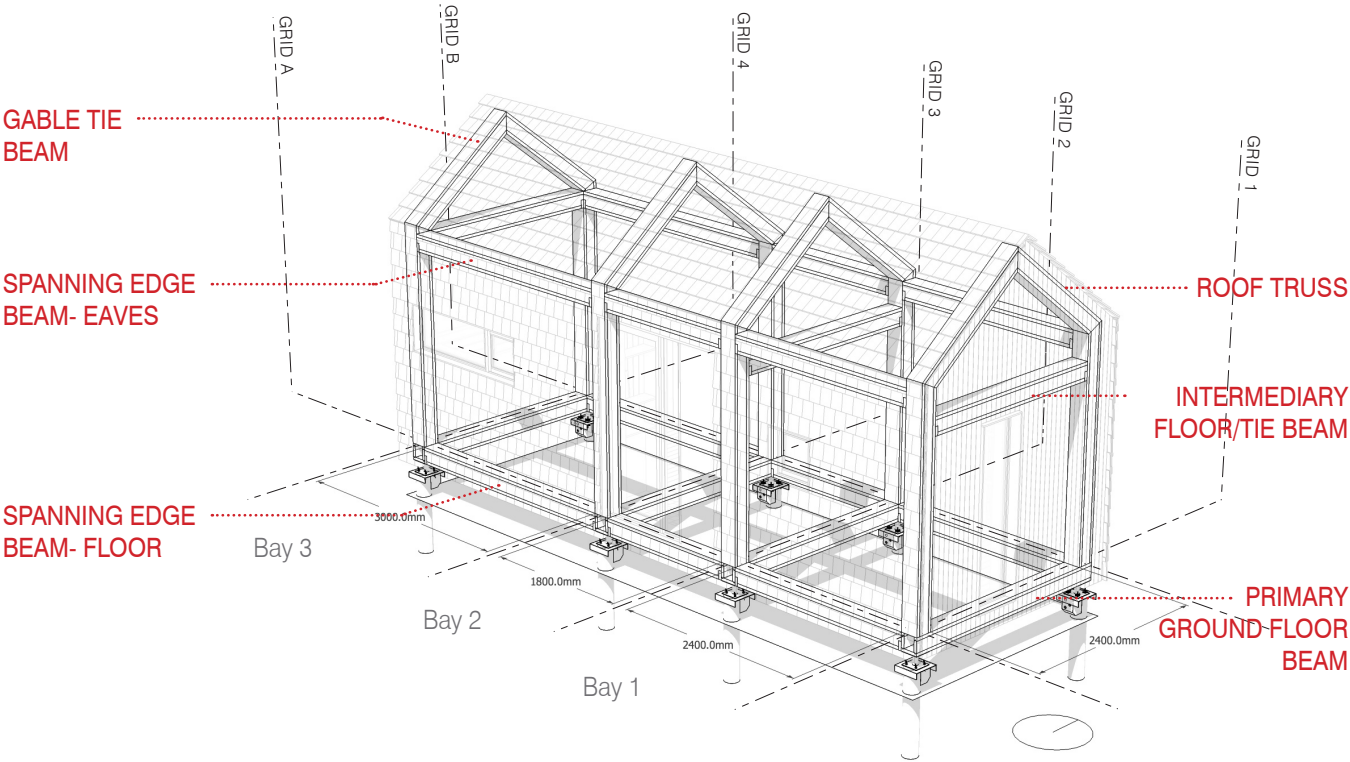
9.05.3 DETAILED DESIGN : PRIMARY STRUCTURE

The primary structure is naturally broken into 3 bays by four portal frames. The primary structure comprises of 6 components;

- 4 x 2.82m primary ground floor beams, spanning north to south
- 8 x 2.4m mitred columns
- 8 x 1.8m mitred roof trusses
- connectors
- spanning edge beams at ground and eaves, spanning east to west between primary north / south 'portals'
- intermediary floor beams, which in gable ends act additionally as tie beams.

Due to the limited maximum clear span of 2.4m, a 210x210mm hollow box section has been employed throughout. In order to facilitate the standardisation of infill panels, a 600mm grid has been applied to the design of the primary structure. This has been applied in both plan and elevation/section, with the structural spacing between structural members being directly divisible by 600mm components. In order to apply this dimensional arrangement in elevation it has been necessary to recycle the existing columns for use as spanning edge beams, and have new columns manufactured to the a revised height. The new columns are therefore designed to a height of 2.61m to the internal face. This dimension makes allowance for a 210x210mm eaves edge beam to leave a structural opening height of 2.4m.

Figure 9.31: Arrangement of Primary Structure



The assembly of each bay will test an alternative setting out and assembly process as follows;

BAY 1

- Internal Dimensions 2.4m x 2.4m
- 2 no 210 x 210mm Sitka Spruce Box Section pitched portal frames at 2.61m centre to centre
- 2 no 210x210mm box sections span between columns in a balloon frame type organisation at a height of 2.1m to form the intermediary floor support.
- The prefabricated components will be assembled in location with primary and edge floor beams fixed to form a ring beam as a self template. With foundation connections fixed to the ring beam, the assembly will be used to set out foundation fixing points.
- The remaining frame components will be assembled individually working from the ground floor platform and, when installed, the intermediary floor. Roof beams will be combined to form a truss with eaves connectors installed and dropped into the open end of the columns.

BAY 2

- Internal Dimensions 1.8m x 2.4m
- 2 No 210 x 210mm Sitka Spruce Box Section pitched portal frames at 2.01m centre to centre.
- A dimensionally accurate template of the primary structure will be assembled and employed to set out the foundation fixing points. Bonded in rods will be measured and installed ready to receive the frame assembly.
- Portal 2 will be installed as part of Bay 1 assembly, therefore portal 3 will be fully assembled locally, lying flat on the ground and rotated vertically into location by hand in a similar manner to the traditional assembly method of cruck framing.

BAY 3

- Internal Dimensions 3.0m x 2.4m
- 2 No 210 x 210mm Sitka Spruce Box Section Portal Frames at 3.21m centre to centre.
- Frame and infill panel installation will be performed in parallel. Ground floor beams and edge beams will be installed on foundations with floor infill panels installed immediately to provide a safe working platform. Columns and wall infill panels are installed in parallel working from the ground floor platform. Eaves beams will then be installed to provide a base for gable panels to be installed providing a dimensionally accurate support for roof trusses to be installed to complete the primary structure.

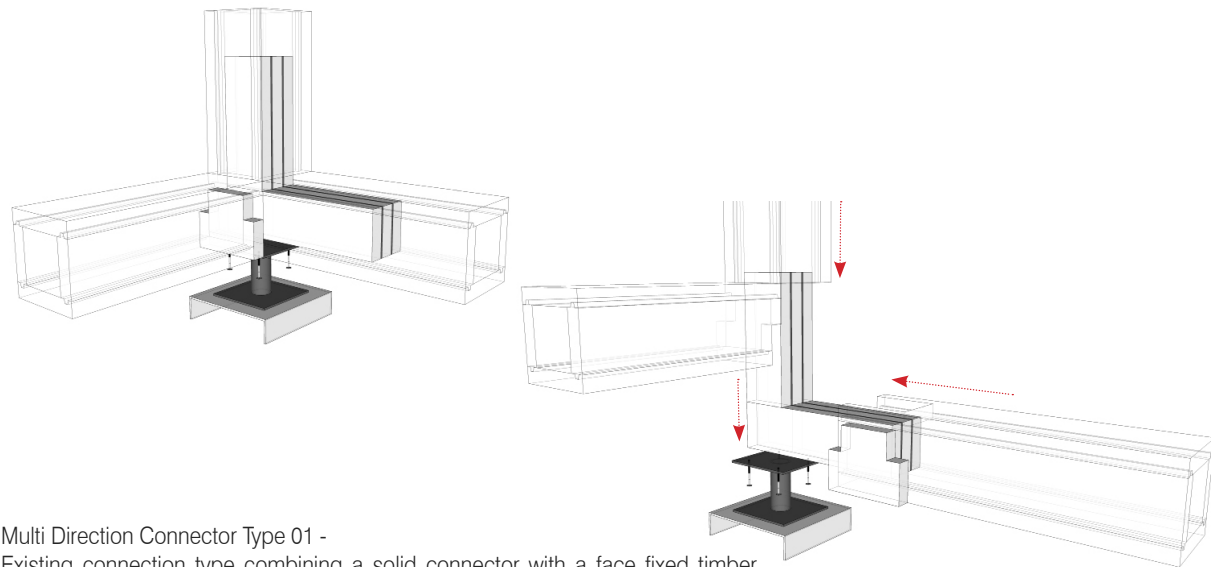


Figure 9.32: Multi Direction Connector Type 01 - Existing connection type combining a solid connector with a face fixed timber shear plate to support spanning box section edge beams. Solid connector arms are slid into the box section hollow of the floor beam and column, and spanning edge beams are simply dropped onto the shear plate connector and fixed.

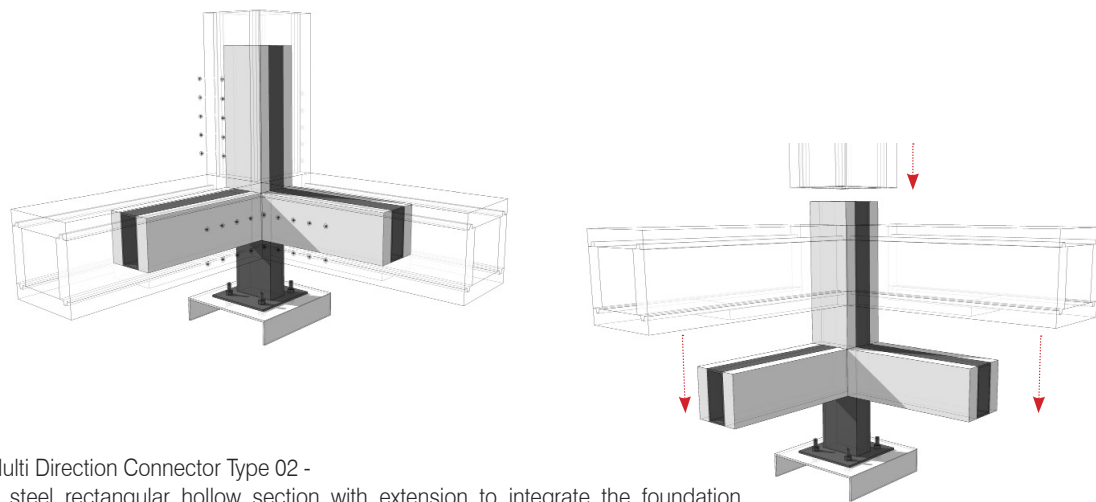


Figure 9.33: Multi Direction Connector Type 02 - A steel rectangular hollow section with extension to integrate the foundation connector is fabricated to suit the required alternative frame junctions and clad with timber fixing cheeks. Floor beams have bottom flanges removed to allow beams to drop down onto the connector and fix through web timbers.

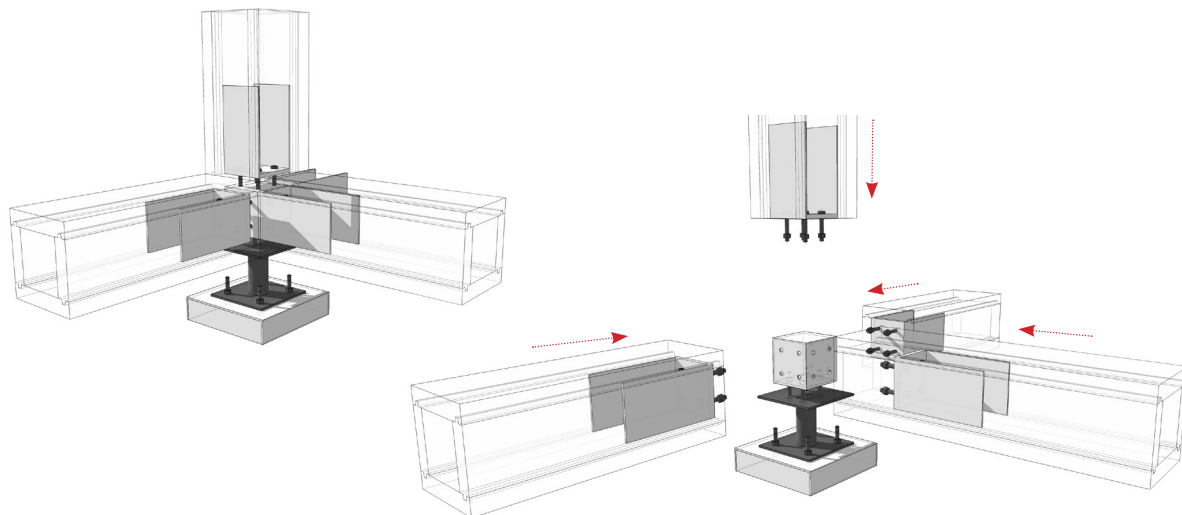


Figure 9.34: Multi Direction Connector Type 03 - Double flitch plate connectors are fixed into the square end of standard box sections and brought to meet at a universal node which is formed and drilled to determine the junction geometry.



Figure 9.35: Steel and softwood hybrid bolt laminated connectors, left over from the construction of the Welsh Smithsonian Pavilion.

CONNECTOR OPTIONS

In addition to box section components, a number of steel and timber hybrid connectors were found to be surplus to the requirements of the Welsh Pavilion. This included 8 no right angle connectors, 8 no 128° eaves connectors and 4 no 104° ridge connectors. The connectors are specifically over engineered to include 2 no 10mm steel plates in order to resolve concerns of uplift on the Mall, identified as a hurricane risk zone. The connectors, although containing steel, provide essentially a similar level of performance as the solid timber, or timber and plywood laminate connectors described and employed elsewhere in the prototypical studies in conjunction with a 40mm thick 'T' shaped shear plate.

This combination of solid timber connector and shear 'T' plate connector has been employed for the construction of the Welsh Passive House and used extensively in the Ty Unnos Modular system. However a number of recurring concerns have been raised by members of the Project Team regarding their application. These include;

- The existing structural joints have a limited load capacity, with all connections operating close to their structural capacity at large spans. Currently these junctions are designed for a two storey frame at 2.7m centres and a 4.2m main span. Shear plate connectors have a very limited capacity in bearing strength and the frame relies considerably on the performance of diaphragm panels to provide racking resistance.
- The thermal efficiency of a solid connector, even in solid timber, raises concerns of cold bridging at node points, particularly in high thermal performance buildings.
- All five box section elements employed in the frame, ie edge beam, floor beam, ground floor column, first floor column and roof truss require a different geometry at each node making the standardisation and interchangeability of box section elements limited.
- The 40mm thickness of the shear plate connectors offers very limited tolerance for inaccuracy in the construction of the frame. As the shear plate is face fixed, it does not have a positive locating point and therefore can be easily misaligned.
- The connectors limit the frame geometry quite significantly as columns, edge beams and floor beams must come together perpendicularly at the node.
- The solid section connector was initially designed for the 210x210mm box section frame of the Ty Unoos Modular system. As larger spans are being proposed using deeper box section beams, the size, weight and quantity of material in the connectors is significantly increasing, potentially making

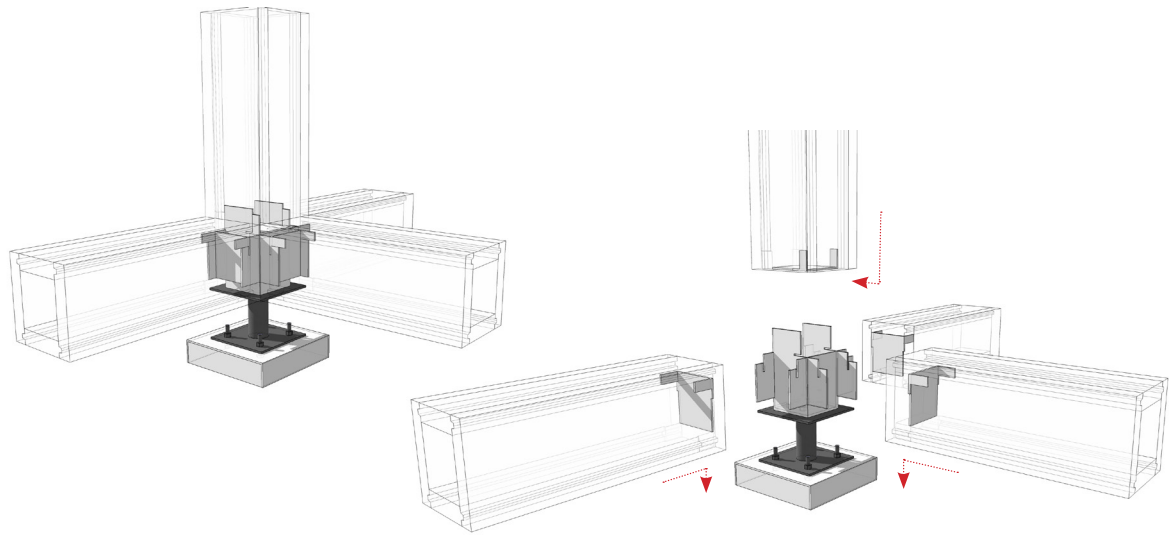


Figure 9.36: Multi Direction Connector Type 04 - Bespoke metal hangers are formed and fixed into the box section hollow and hung or clipped into a formed metal mode.

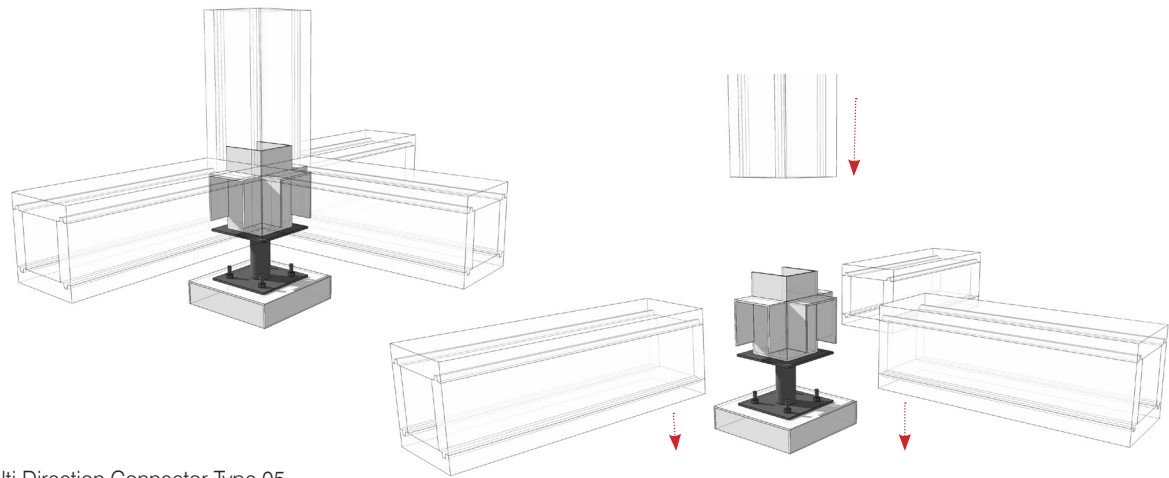
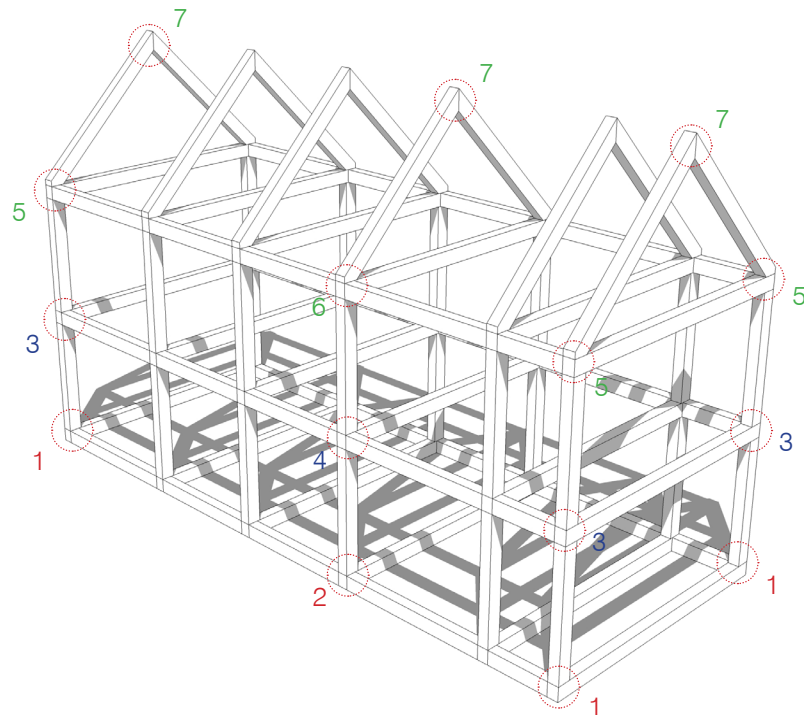


Figure 9.37: Multi Direction Connector Type 05 - A formed steel connector is cut and welded with short connector arms to form the geometry of the junction. Box sections are simply located and fixed onto arms.

Figure 9.38: Illustration of alternative connection geometries required in a typical two storey pitched roof structure.



1. Corner Ground Floor to Columns
2. Middle Ground Floor to Columns
3. Corner Intermediary Floor to Columns
4. Middle Intermediary Floor to Columns
5. Corner Column to Roof Truss
6. Middle Column to Roof Truss
7. Ridge Connector



Figure 9.39: Bolted timber multi direction connector proto-typed at half scale

components less appropriate for manual handling.

- The general assembly sequence of the primary structure.

Following extensive discussions with Burroughs it is clear that alternative structural connections are unlikely to perform with any significant increase in capacity as the limiting factor is typically the connection between box section and connector. The emphasis therefore is better placed on the design of racking or diaphragm support to the primary structure.

Burroughs were appointed to propose and review a number of alternative connection options, the findings of which were presented in Report 2252 Ty Unnos Frame Connection Development. 6 frame connections were proposed and compared in the report, a number of which were put forward by myself. A number of alternative connectors are illustrated in figures 9.32 - 9.37. The study focused most critically on the thermal performance of the proposed junctions and buildability.³

Of the options discussed in the report, Type 03 was considered to offer the greatest potential by myself. The junction comprises of two components; a node, and a double flitch plate set to the geometry of the hollow of the box section. Drawing on the precedent of geodesic dome structures, the double flitch plate is designed to be fixed into the square end of each box section length and brought together to bolt into a node, which through its geometry and fixing points, determines the geometry of the junction. Of particular advantage in this arrangement is the ability for all components to be prefabricated with identical end conditions for each junction of the frame. However, the report finds that the junction would be complex to manufacture and subsequently prohibitively expensive.

The report therefore concludes that two connector options are preferable, a 3d steel connector or steel plate connector, shown in Figures 9.40 and 9.41 respectively.⁴ The steel plate connector employs a number of standard right angled section and flat steel plates face fixed directly between columns and beams. The connector significantly improves the thermal efficiency of the junction as steel work can be placed so as to not make direct continuity from warm to cold sides of the insulation. However there are a number of significant compromises affecting this connection type, most significantly steel sections project into the structural opening of infill panels and openings and will subsequently effect the design and manufacture of infills, as realised in the Ebbw Vale Passive House.

The 3D steel connector however successfully resolves a number of the concerns identified by the Project Team including improved accuracy and buildability of

3 Burroughs, *Ty Unnos Frame Connection Development Report Document* (Cardiff: Burroughs, 2011) p.1.

4 Ibid., p.10.

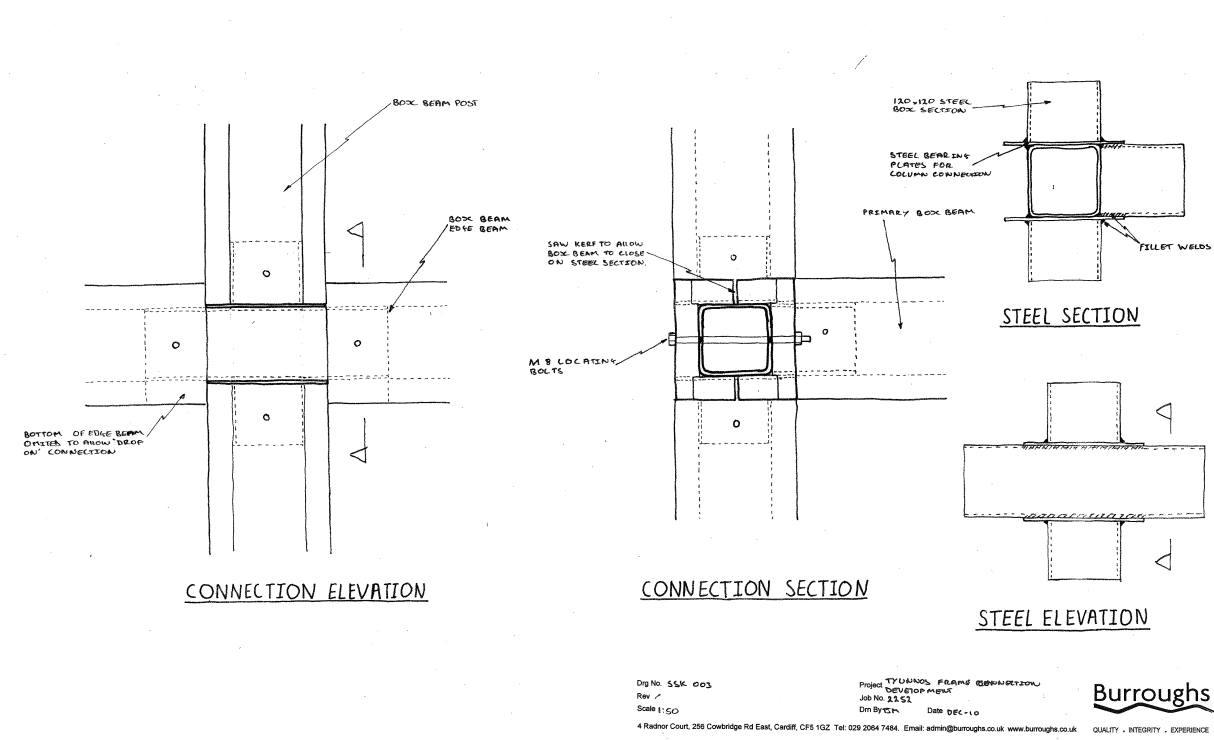


Figure 9.40: Steel 3 Dimensional hollow section connector proposed by Burroughs.

the junction. A standard frame geometry such as that employed for the Ebbw Vale Passive House will require a minimum of 7 alternative connector geometries, as demonstrated in Figure 9.38. The manufacturing costs of a multi direction steel connector are likely to be more expensive than those associated with the existing solid timber connectors.

In addition the proposal fails to fully resolve the potential for thermal bridging as steel is likely to connect cold and warm sides of the insulation. There is potential to reduce this conflict through the inclusion of high performance insulations into the prefabricated connector.

The general conclusion of this ongoing study is that little progress can be made on the design of a revised connector without the assistance of thermal modelling on existing and proposed junctions. With a greater knowledge of the actual thermal performance at nodes, proposed connectors can be tailored to improve performance, or alternative approaches considered.

RESOLVED DESIGN

Bay 1 of the primary structure will make use of existing solid connectors and shear plate connectors in order to assess whether the reservations held by the Project Team warrants the necessary investment in prototyping and development costs associated with a more involved jointing system.

It was initially intended that the remaining structures for bay 2 and 3 would employ a prototype multi directional steel connector similar to that shown in Figure 9.33. However it was not possible to confirm a specification and design in the limited timescale. It is therefore proposed that this form of connector will be incorporated into a future construction to test particularly the ease of buildability. In addition, funding has been received to complete thermal modelling on the existing timber and steel solid section connector and shear plate connector and may be extended to other options as required.

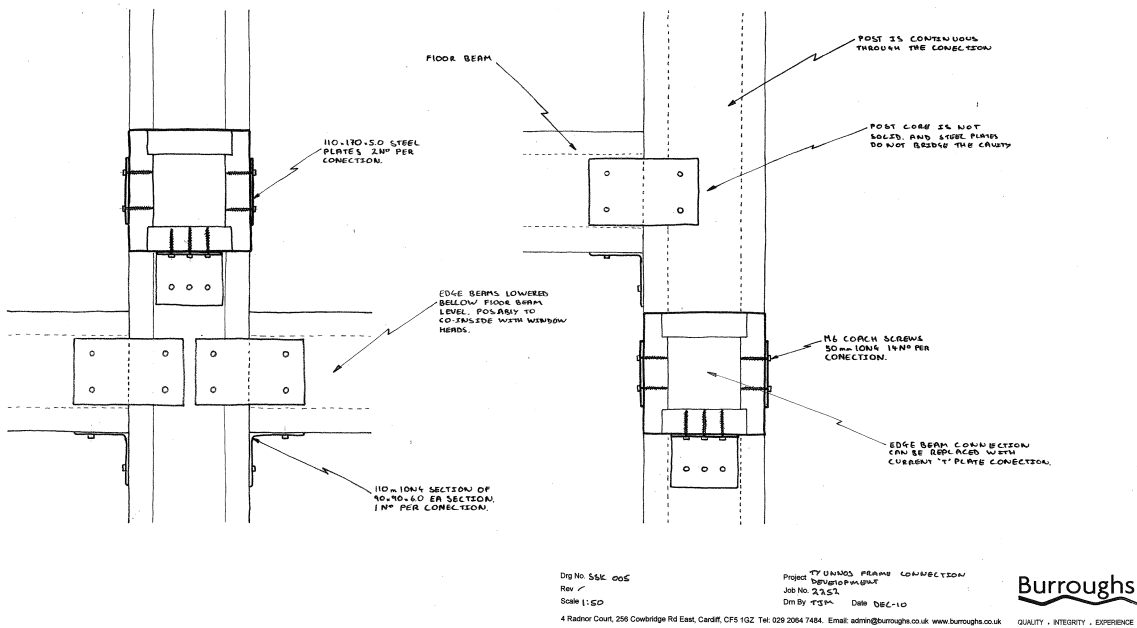


Figure 9.41: Steel plated primary structural connection proposed by Burroughs

9.05.4 DETAILED DESIGN : SECONDARY STRUCTURAL LADDER BEAM

Approximately 2.5 m³ of Welsh Softwood was purchased from Pontrilas Timber in the form of a 125x20mm planed half lap board in lengths up to 3.0m. The timber is a mixture of softwoods, with the majority identified as Sitka Spruce, however the sample includes a high proportion of Larch, with smaller samples of Douglas Fir and Scots Pine. It is clean ungraded stock without preservative treatment, which has been stored for a number of months in a good storage environment. A selection of timber lengths were checked for moisture content with a range of 18-24%.

Drawing S/SK/013, Figure 9.42, shows the ladder beam design as specified by Burroughs for an initial test run manufactured by Pontrilas Timber for testing by Trada. Under normal circumstances this would make use of standard 125x20mm square edge falling boards ripped into two timbers of 60x20mm to provide boom timbers with standard 100x20mm square edge timber cut down for web timbers. An alternative ladder beam section was derived in order to make use of the available half lap material. Figure 9.43 shows the revised section. In this case the 125x20mm half lap board is ripped into two sections including the half lap to give an overall section of 55x20mm. The half lap profile has also been removed to provide a 95x20mm section for web timbers. Due to its reduced section, the revised ladder beam will have a lower bearing capacity. However waste resulting from processing to this dimension will be significantly reduced from the 40% created by processing to the original section.

Each ladder comprises of three components;

- top and bottom boom timbers, 4 in total,
- vertical orientated web timbers, the number of which is determined by web spacings and ladder length,
- Infill boom timbers, which sit between web timbers and boom timbers and act primarily as a spacer.

Drawings AC(0)102, AC(0)105-108 show a range of alternative ladder beams shown in relation to wall and floor plates. The studio is designed to a strict dimensional coordination with all elements designed to a nominal 600mm grid. The setting out dimensions for all ladders are therefore designed as intervals of 600mm, ie 1200mm, 1800mm, 2400mm, 3000mm. However within this dimensional organisation, additional timbers such as wall and floor plates may be accommodated to provide a method of fixing ladders/panels to the primary box section structure.

Essentially there are four ladder beam geometries trialled in the studio;

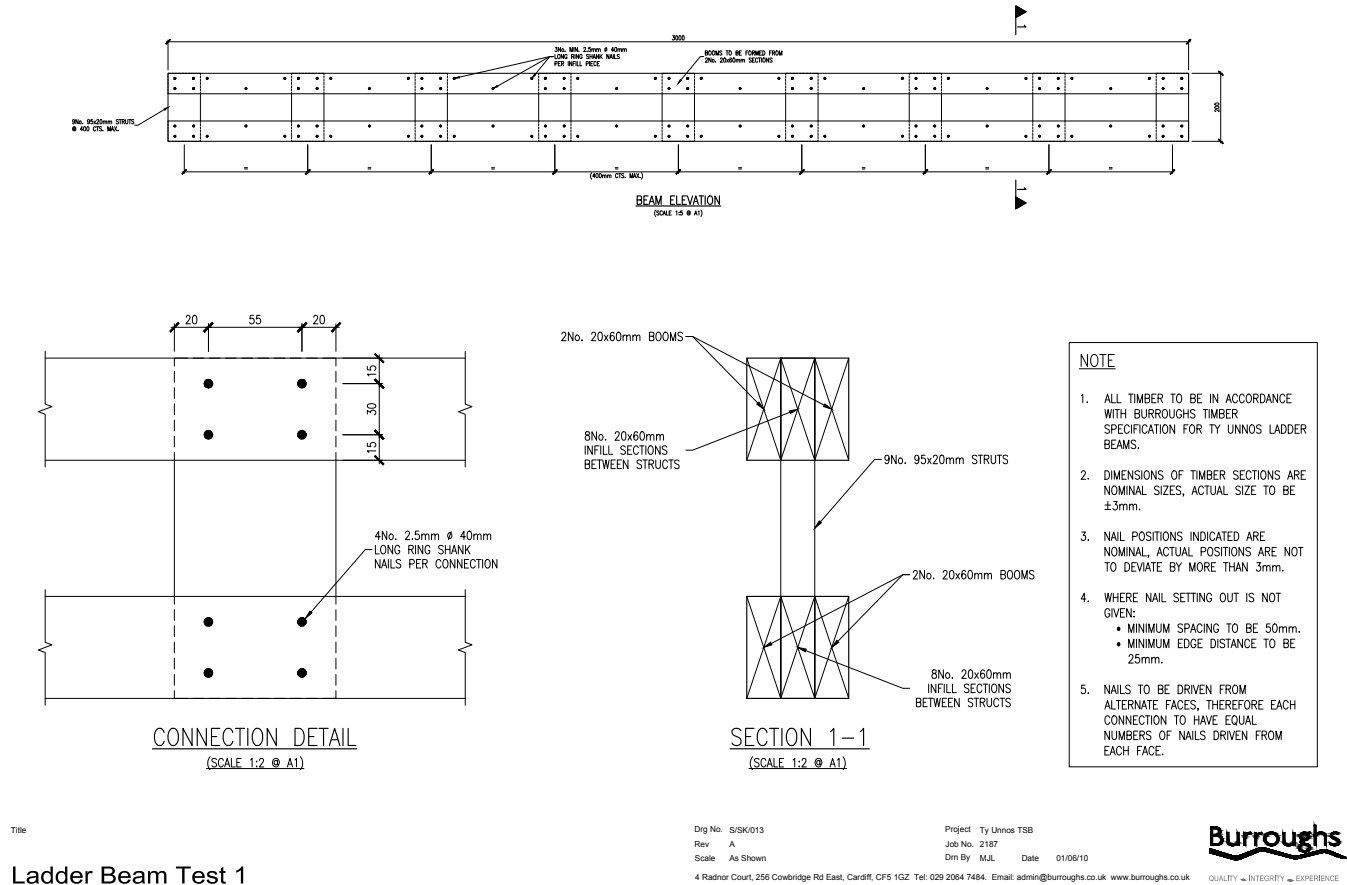
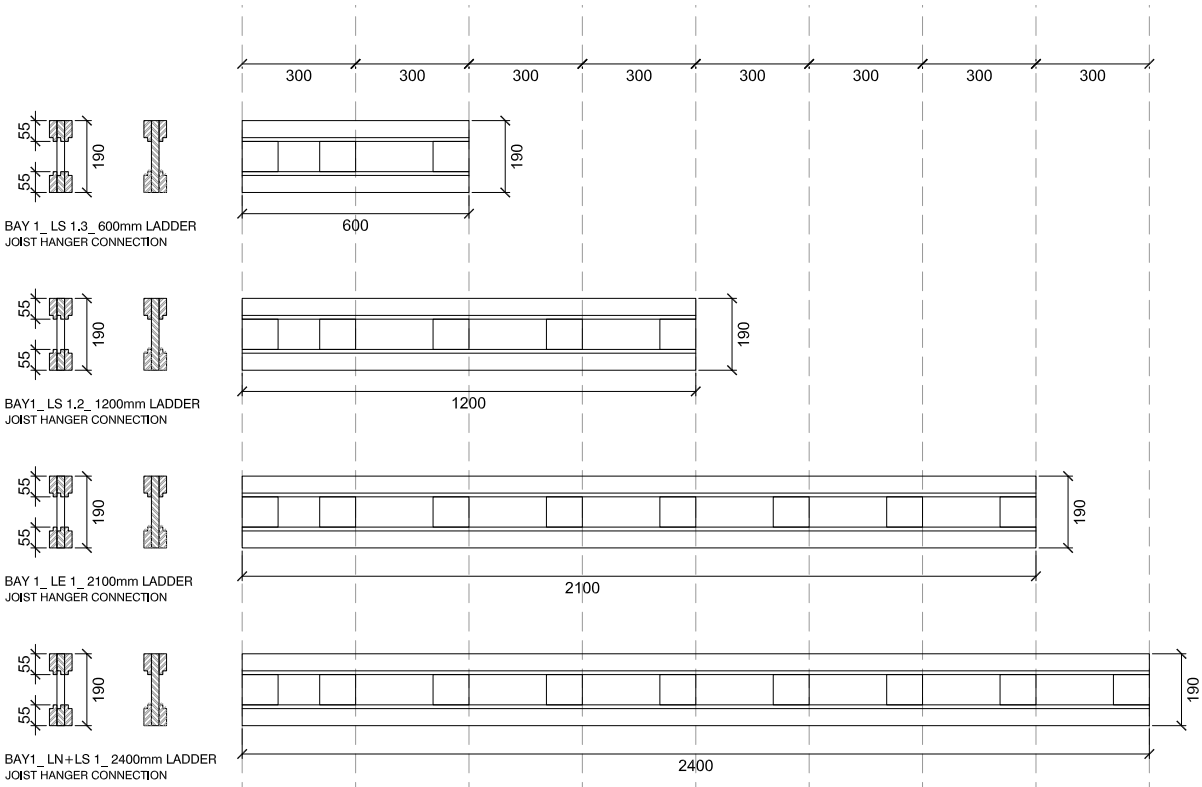


Figure 9.42: Proposed Ladder Beam Type 02 arrangement.

Figure 9.43: Revised Ladder Beam Type 02 arrangement to make use of 125x20mm halflap boards



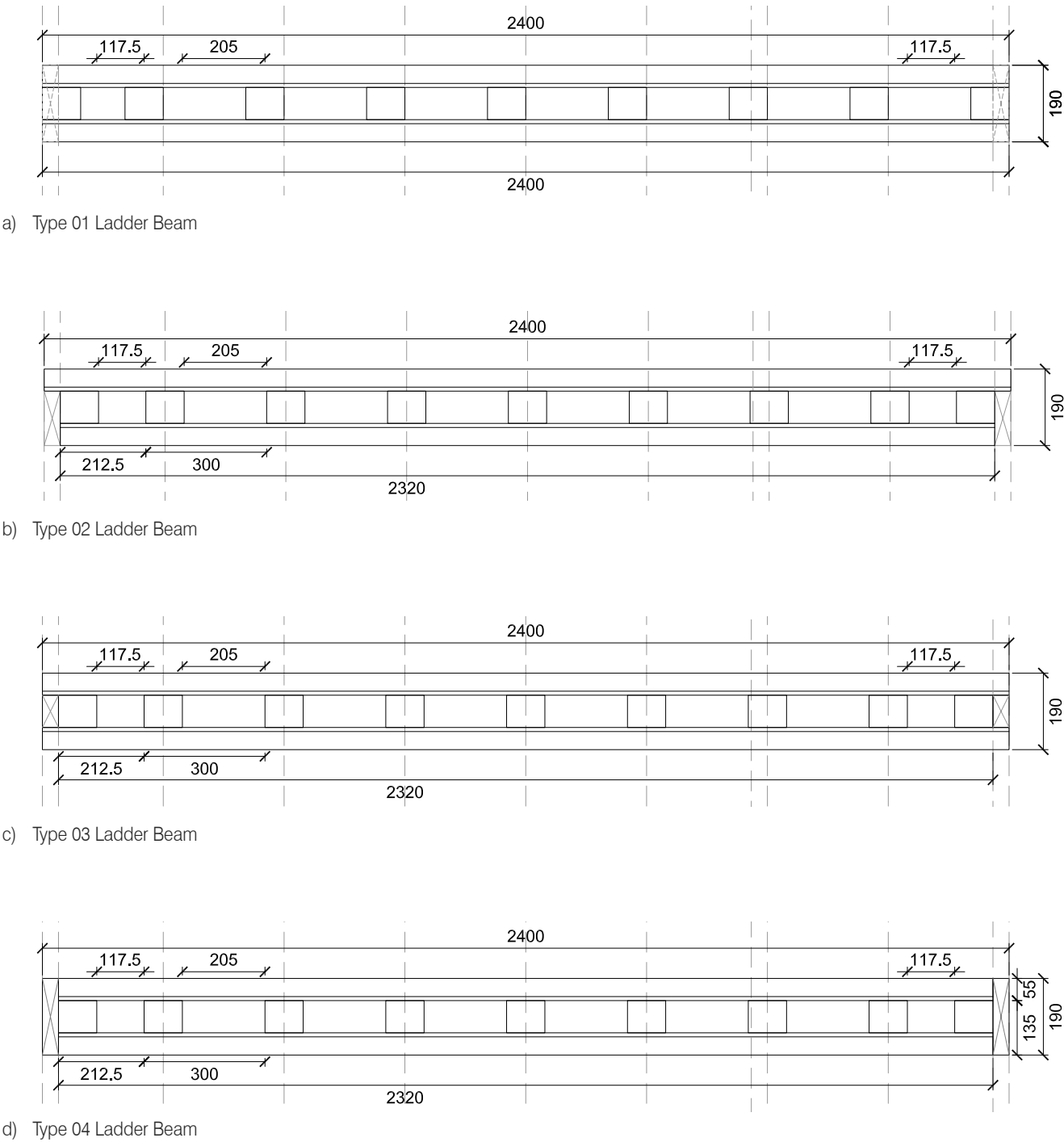


Figure 9.44: Alternative ladder beam arrangements to incorporate end plates



Figure 9.45: Ladder Beam Type 01 employed for the construction of a Ty Unnos Modular unit ceiling, prefabricated into a frame with fixing plate between ladder webs.

TYPE 01- SHOWN IN DWG AC(0)102. FIGURE 9.44a.

A full length ladder set out to the standard dimensional grid with finished nominal lengths of 1200mm, 1800mm, 2400mm, 3000mm. Ladders terminate in a web at each end with top and bottom full length booms. The first web spacing is reduced by the web width to enable all subsequent webs to be set at 300mm centres. This geometry enables ladders to be manufactured to a set length, say 3m, and simply trimmed to length in intervals of 300mm whilst still maintaining the even spacing of web timbers.

TYPE 02 - SHOWN IN DWG AC(0)105. FIGURE 9.44b.

Ladders are designed with an extended top boom at both ends. End web timbers are inset by 40mm from the dimensional grid to allow a 135x40mm wall plate to be accommodated within the dimensional grid. A number of alternative webs were trialled including an extended section of OSB and plywood. See Figure 9.46b and c.

TYPE 03 - SHOWN IN DWG AC(0)107- LN3.2. FIGURE 9.44c.

Ladders are designed with an extended top and bottom boom at both ends. End web timbers are inset by 40mm to provide for an 80x40mm wall plate to be accommodated between boom timbers within the dimensional grid. This is based on the geometry of the Ty Unnos Ladder Type 01 used by the Ty Unnos Modular system. See Figure 9.46a.

TYPE 04 - SHOWN IN DWG AC(0)107- LN3.3 + LN3.4. FIGURE 9.44d.

Ladders are designed with a square edge, reduced within the dimensional grid by 40mm each end to accommodate a 190x40mm full width plate or two 55x40mm plates, or to accommodate a ladder beam section employed as a wall plate.

Figure 9.46: Alternative end geometries of ladder beams;

a) Softwood web and infill pieces to recreate the Type 01 arrangement used for the Ty Unnos Modular system.



b) Top boom is extended by 40mm over solid timber bearing plate.



c) End softwood web is replaced with an extended plywood end section to provide extra rigidity to extended top boom.



Figure 9.47: Proposed ladder beam assembly table

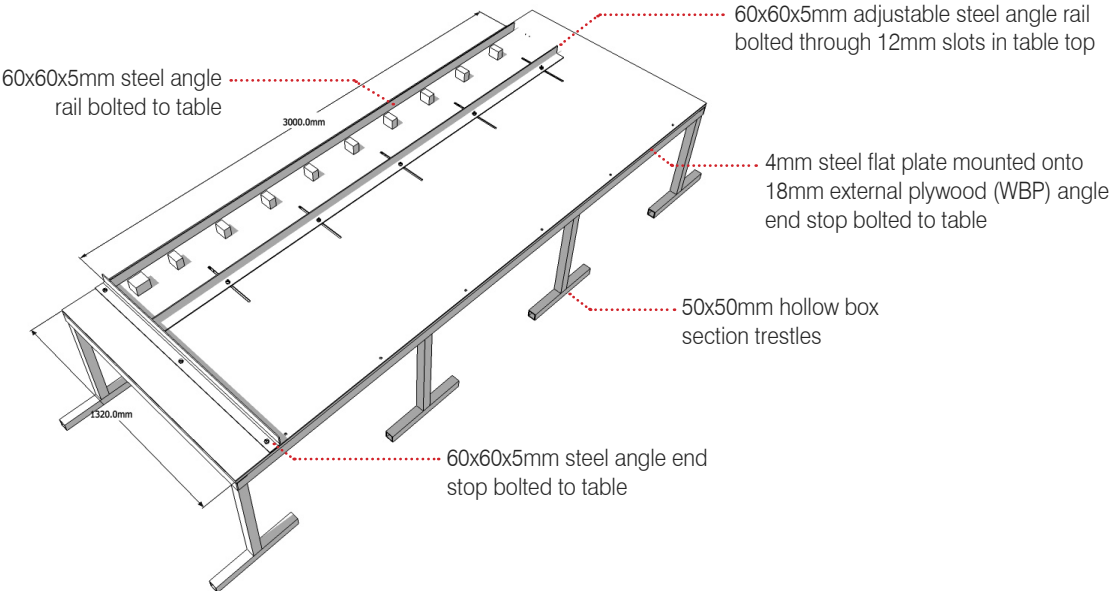
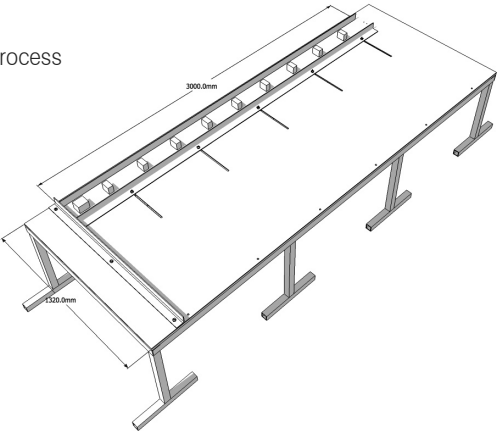
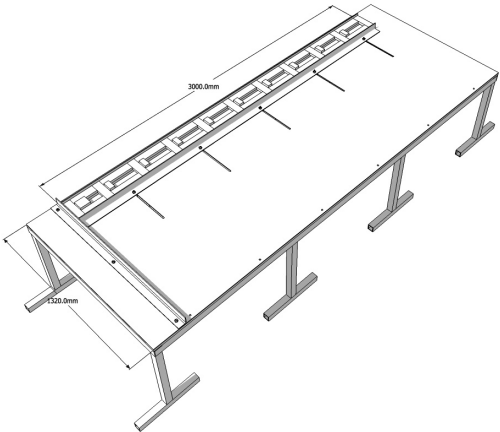


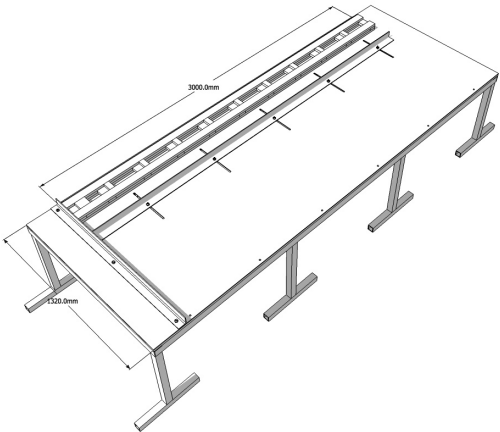
Figure 9.48: Proposed assembly process using assembly table



a) Adjustable rail is fixed to correct depth and timber blocks installed as web spacers



b) Timber booms, web timbers and infills are inserted into jig in sequence



c) Once assembled a nail gun is passed along the ladder's length to the nailing pattern as set out in DWG ... Once nailed the bottom rail is released and the ladder removed from the jig

Figure 9.49: Completed ladder beam table set up adjacent to the Old Sawmill workshop.



9.05.5 DETAILED DESIGN : LADDER BEAM JIG

Early prototypes of the laminated ladder were assembled and nailed by hand, using common workshop facilities to set out and hold the assembled components. Due to the large number of ladders required for the studio it was proposed that a simple assembly table and jig would be essential to enable this process to be accurately and efficiently repeated. The jig would need to provide a robust surface that could crimp pneumatic fired nails safely and without significant damage, and have a fixed arrangement that allowed the efficient assembly of ladder beams of differing geometries without significant measuring and checking for accuracy whilst ensuring a repetitive level of quality.

The proposed jig therefore is a large assembly table of approximately 3.6 x 1.3m formed from a flat sheet of 4mm steel plate. A rail and end stop of steel angle act as parallel and perpendicular stops providing accurate straight edges for the assembly of ladder beams up to 3m long. A second longitudinal rail, located in profiled slots in the table, provides a parallel guard that can be adjusted for a range of ladder beam depths. The table is purposefully oversized to allow for multiple uses but could be reduced to a width of 0.6m if desired.

Neo Fabrications were commissioned to manufacture the jig including a supporting frame of steel angle section and 4 square hollow section trestle legs for a total cost of £900. In addition to the primary steel elements, a sheet of 18mm external plywood was layered under the steel plate table for extra rigidity and hardwood spacers were arranged as web spacers, acting to force boom timbers against the top and bottom rails whilst setting out webs at 300mm centres.

Figure 9.50: Preparing ladder beam table to receive hardwood spacers;

a) Steel table is punched to set out spacer positions.



b) Table is predrilled for fixings.



c) Spacers are accurately set out and fixed using a right angle square.



9.05.6 DETAILED DESIGN : SECONDARY STRUCTURAL INFILL PANELS

Prototypical Studies, described in Chapter 8.0, have provided a broad range of useful findings regarding the design and assembly of infill panels. Due to the nature of these projects, the resultant proposals have failed to deliver a fully resolved design for a standardised and prefabricated whole house system which makes use of a high percentage of homegrown timber and engineered timber components. The Rural Studio is identified as a perfect opportunity to develop a full resolved system through the trial of a number of alternative prototype arrangements.

Alternative detailed designs and specifications have therefore been applied to each structural opening, in order to test panel geometry in terms of prefabrication and installation, fixing methods and efficiency of assembly. These studies are summarised in Table 9.4.

In order to focus these studies, each of the three bays has concentrated on a specific design theme, and it is these primary themes which will be discussed in greater detail;

Bay 1 - the integration of proprietary fixings - Study 3.3

Bay 2 - closed panel systems - Study 3.2.

Bay 3 - open panel systems and alternative sheathing methods- Study 3.2.

The Prototypical Studies have conclusively identified that the efficiency and viability of a component system is critically dependent of the ability for infill proposals to resist and transfer structural diaphragm loads. The integration of racking potential has therefore formed an underlying design study through each of these themes.

Drawings AC(2)101 - AC(2)701 show a selection of the proposed panels designed for each opening.

Figure 9.51: Structural arrangement of the proposed studio.

- 1. Bay 1 Floor
- 2. Bay 2 Floor
- 3. Bay 3 Floor
- 4. Bay 1 South Wall
- 5. Bay 2 South Wall
- 6. Bay 3 South Wall
- 7. Bay 1 South Roof
- 8. Bay 2 South Roof
- 9. Bay 3 South Roof
- 10. Bay 1 East Wall
- 11. Bay 3 West Wall
- 12. Bay 1 East Gable
- 13. Bay 3 West Gable
- 14. Bay 1 North Wall
- 15. Bay 2 North Wall
- 16. Bay 3 North Wall
- 17. Bay 1 North Roof
- 18. Bay 2 North Roof
- 19. Bay 3 North Roof

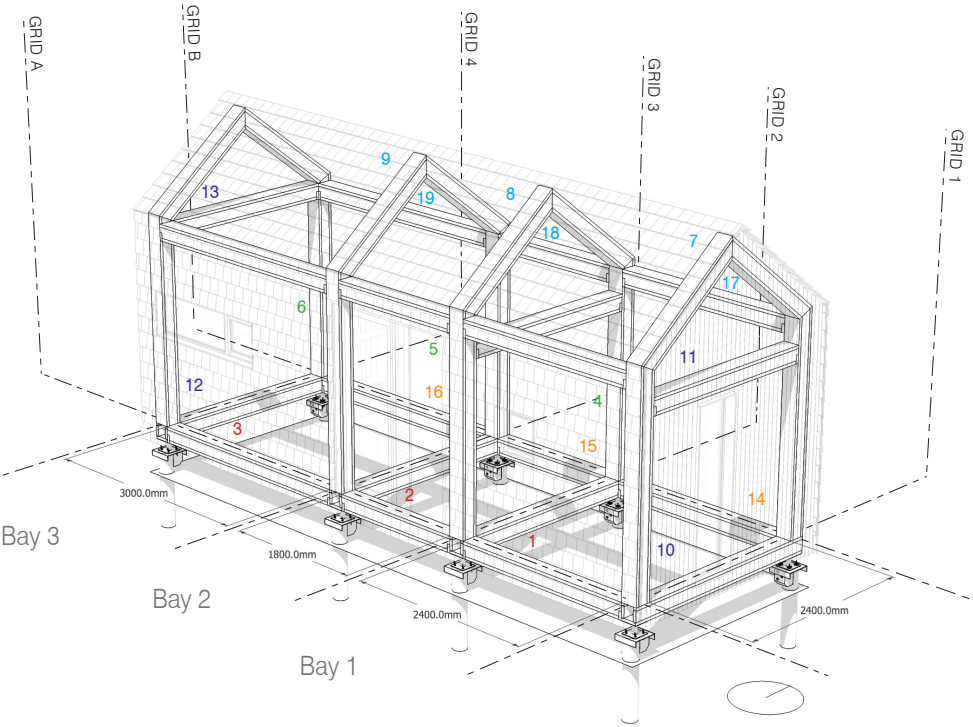


Table 9.4: Summary of infill panel design trials

Location Bay	Infill	Element	Primary Trial	Description	Connection between Panels	Sheathing Type External	Sheathing Type Internal	Diaphragm Connection Type Horizontal (Top + Bottom)	Vertical (Side)
1	1	Floor	<ul style="list-style-type: none">Proprietary fixingsAlternative diaphragm / sheathing board arrangements	Open Panel	18mm OSB Laid laterally across joists	18mm OSB prefabricated into open panel	18mm OSB laid laterally across joists		
1	10+11	Wall - East		600mm Open Panel	Batten fixed internally to panel edge, screwed from both panels	Single sheet of 18mm OSB prefab as open panel - notched to fit over joist hangers	Single sheet of 18mm OSB applied on site without overlaps	Overlaps provided due to reduced 2.1m height	Corner panels have 700mm external sheathing to overlap post
1	4	Wall - South		600mm Open Panel	Batten fixed internally to panel edge, screwed from both panels	One layer of 9mm OSB prefab as open panel with 9mm OSB applied on site with staggered joints	Single sheet of 18mm OSB applied on site without overlaps - notched to fit over extra deep joist hangers	Staggered layers of 9mm OSB overlap frame	Staggered layers of 9mm OSB overlap neighbouring panels and frame
1	14	Wall - North		Prefab as a full bay open panel including top and bottom spanning edge beams to be combined with portal frames on site	N/A	One layer of 9mm OSB prefab as full size open panel with 9mm OSB applied on site with staggered joints	Single sheet of 18mm OSB applied on site without overlaps	Staggered layers of 9mm OSB overlap spanning edge beams	Staggered layers of 9mm OSB overlap neighbouring ladders and frame
1	7+17	Roof		600mm Open Panel	None	Single sheet of 18mm OSB prefab as open panel with OSB trimmed to allow access to joist hangers externally	Single sheet of 18mm OSB applied on site without overlaps - notched to fit over extra deep joist hangers		
2	2	Floor	<ul style="list-style-type: none">Closed Panel SystemIncorporating provision for diaphragm capacity	Closed panel system of 600mm panels	Loose tongue of 9mm plywood in grooved panel edge top and bottom, panels dropped into location and slid together	Single sheet of 18mm OSB prefab as closed panel extended over panel plate to width of the structural opening	Single sheet of 18mm OSB prefab as closed panel trimmed to fit within bearing plates fixed directly to P+B frame	Screws installed from above through panel plate into bearing plates fixed directly to P+B frame	No overlap to enable a panel system set out to 600mm dimensional grid
2	5	Wall - South		Closed panel system of 600mm panels	Loose tongue of 9mm plywood in grooved panel edge top and bottom	Single sheet of 18mm OSB prefab as closed panel extended over panel plate	Single sheet of 18mm OSB prefab as closed panel trimmed to fit within top and sole plate	Screws installed from exterior through panel plate into top and sole plate fixed directly to P+B frame	External sheathing of corner panels overlap columns resulting in 700mm wide external sheathing
2	15	Wall - North		Closed panel system of 600mm panels	Loose tongue of 9mm plywood in grooved panel edge top and bottom	Single sheet of 18mm OSB prefab as closed panel extended over panel plate	Single sheet of 18mm OSB prefab as closed panel trimmed to fit within top and sole plate	Screws installed from exterior through panel plate into top and sole plate fixed directly to P+B frame	No overlap to enable a panel system set out to 600mm dimensional grid
2	8+18	Roof		Closed panel system of 600mm panels with a non standard panel at ridge to fill the roof pitch	Loose tongue of 9mm plywood in grooved panel edge top and bottom	Single sheet of 18mm OSB prefab as closed panel extended over panel plate to width of the structural opening	Single sheet of 18mm OSB prefab as closed panel trimmed to fit within bearing plates fixed directly to P+B frame	Screws installed from above through panel plate into bearing plates fixed directly to P+B frame	No overlap to enable a panel system set out to 600mm dimensional grid
3	3	Floor	<ul style="list-style-type: none">Alternative sheathing materials	Open panel system of 600mm panels using Spruce T+G as alternative sheathing	Panels connected by fixing through neighbouring ladder beams from within the panel	18mm Spruce T + G boards fixed laterally or perpendicularly to ladder beams employing substructure of noggins and plates	18mm Spruce T + G boards fixed on site laterally or perpendicularly to ladder beams employing substructure of noggins and plates	Screws installed from interior of panel through panel plate directly into P+B frame	Screws installed from interior of panel through ladder directly into P+B frame.
3	6	Wall - South	<ul style="list-style-type: none">Alternative diaphragm / sheathing board arrangementsAlternative wall plate geometries	Open panel system of 600mm panels testing alternative arrangements of head and sole plates and sheathing overlaps	Panels connected by fixing through offset external sheathing into neighbouring ladder	Single sheet of 18mm OSB prefab as open panel extended over top + sole plate and offset by 30mm to overlap neighbouring ladder	Single sheet of 18mm OSB applied on site extended over top + sole plate and offset by 30mm to overlap neighbouring ladder	Screws installed from interior of panel through top + sole plate directly into P+B frame	Screws installed from interior of panel through ladder directly into P+B frame.
3	16	Wall - North	<ul style="list-style-type: none">Alternative diaphragm / sheathing board arrangementsAlternative wall plate geometries	Open panel system of 600mm panels testing alternative arrangements of head and sole plates and sheathing overlaps	Panels connected by fixing through offset external sheathing into neighbouring ladder	Single sheet of 18mm OSB prefab as open panel extended over top + sole plate and offset by 30mm to overlap neighbouring ladder	Single sheet of 18mm OSB applied on site extended over top + sole plate and offset by 30mm to overlap neighbouring ladder	Screws installed from interior of panel through top + sole plate directly into P+B frame	Screws installed from interior of panel through ladder directly into P+B frame.
3	12+13	Wall - West	<ul style="list-style-type: none">Application of a closed panel system to test arrangement and construction sequence when considering openings	Closed panel system of 600mm panels	Loose tongue of 9mm plywood in grooved panel edge top and bottom	Single sheet of 18mm OSB prefab as closed panel extended over panel plate	Single sheet of 18mm OSB prefab as closed panel trimmed to fit within top and sole plate	Screws installed from exterior through panel plate into top and sole plate fixed directly to P+B frame	No overlap to enable a panel system set out to 600mm dimensional grid
3	9+19	Roof		Open panel system of 600mm panels with a non standard panel at ridge to fill the roof pitch	Panels connected by fixing through ladder into neighbouring ladder from within panel	18mm OSB, pieced to extend panel length, prefab as open panel extended over panel plate and frame	18mm OSB applied on site without overlaps - pieced to extend panel length	Screws installed from interior of panel through panel plate directly into post and beam frame and fixed through external sheathing directly into P+B frame	

9.05.6.1 SHEATHING BOARDS

In order for the panels to provide racking resistance Burroughs have advised that sheathing boards must overlap the primary structure in order to allow fixings to be directly installed through sheathing boards into the primary structure. There are a number of challenges that need to be overcome if panels are to be designed to incorporate overlaps efficiently;

- The geometry of panels are determined by three factors; the standard dimensions of available sheathing boards, the overlaps required to provide assistance in resisting racking forces and the spatial requirements of the room type. Although OSB is available in oversized panel sizes such as 2.7x1.2m it has been the Project Team's experience that this is rarely available in the UK in small quantities. The 2.4m panel size (2.44x1.22m) is available from most timber merchants. However this panel size poses a concerning restriction to panel design specifically panel height, when single boards are required to overlap the primary structure at top and bottom. Once detailed with a sheathing board, service zone and finishes, the floor to ceiling height can be reduced to approximately 2300mm. The restrictive nature of this height is illustrated by the London Housing Design Guide adopting a minimum floor to ceiling height of 2.6m for all habitable rooms.⁵
- The inclusion of overlaps largely negates the positive material efficiencies achieved by employing a dimensionally coordinated grid to determine structural openings and infill panel sizes. A 600mm wide panel for example would become a 660mm wide panel to enable an appropriate overlap to one edge, thus resulting in a 580mm off cut unsuitable for use for further panels.
- Sheathing boards are commonly used by timber frame manufacturers as an efficient and accurate method for squaring up stud panels, with studs and rails lined up against panel edges and manipulated to match the perpendicular edges of the panel. This is not possible with overlapped panels, as edges are set at a distance away from structural members. Manufacturing processes are therefore required to accurately assemble and hold structural members prior to the accurate positioning and fixing of sheathing boards. This issue was clearly illustrated in the experiences of the Welsh Passive House, with KJJ stating that the resultant process was time consuming and challenging to achieve a good level of accuracy.

FINDINGS

The design and assembly of the Prototypical Studies have demonstrated that it is

5 Mayor of London, *London Housing Design Guide: Draft for Consultation 2009* (London: London Development Agency, 2009), p. 55.

simply not possible to detail a prefabricated closed panel that overlaps the frame to the interior and exterior of the frame without the integration of the primary structural elements into the prefabricated panel. Whilst this may be feasible, it would have to be performed at the scale of full wall sections and therefore require substantial lifting equipment during construction. A smaller scale panel system must therefore be considered either as;

- open panels with overlapping internal sheathings applied on site capable of providing diaphragm resistance,
- closed panels with internal panels not overlapping the primary structure and providing diaphragm capacity,
- simplified thermal panels that do not provide any additional diaphragm capacity.

In addition, there would appear to be two alternative methods for ensuring a sheathing panel is capable of transferring racking loads;

- Applying multiple layers of staggered and offset sheathing boards, to make up the desired geometry and scale of panel, with diaphragm capacity ensured by fixings installed through the multiple layers of the sheathing.
- Ensuring that a single continuous or suitably jointed sheathing panel is capable of connecting directly to the required primary structural elements, subsequently restricting geometry to the available material dimensions.

The final option of separating the multiple functions of the infill panels to create a simplified thermal panel in conjunction with an additional component capable of providing diaphragm resistance, may potentially offer the opportunity to make use of a whole Sitka Spruce based panel as proposed initially.

Following advice from Burroughs, the proposal to employ a spruce based panel as a rackable solution has been dismissed due to the extremely low diaphragm capacity provided by a sheathing of this type.

These alternative approaches to the provision of diaphragm resistance will therefore be applied to each individual infill bay of the structure and tested for material, manufacturing and assembly efficiency. Table 9.4 and drawings AC(C)201 - AC(2)502 illustrate the alternative methods in further detail.

9.05.6.2 BAY 1 - PROPRIETARY FIXINGS

Proprietary fixings such as joist hangers are becoming increasingly applied in the construction of multiple unit housing developments as they offer a predictable and efficient method of connecting spanning joists with a variety of forms of load bearing structure. It is proposed that for homegrown engineered timber components to be generally applicable within the construction industry they must be compatible with commonly available proprietary fixings. In addition it is

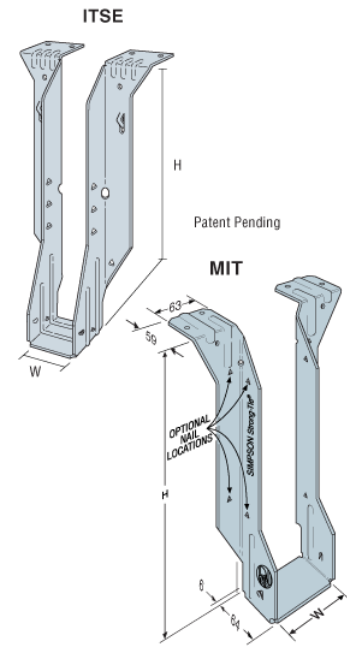


Figure 9.52: ITSE and MIT Top Flange Hangers designed for engineered joists by Simpson Strong Tie

Source : Simpson Strong Tie

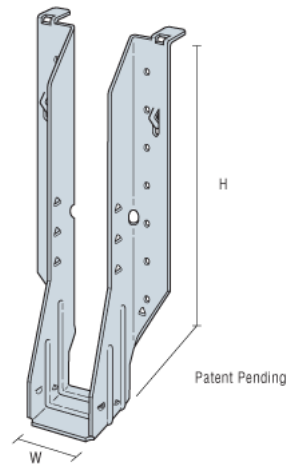


Figure 9.53: IUS Face Mount Hangers designed for engineered joists by Simpson Strong Tie

Source : Simpson Strong Tie



Figure 9.54: 18mm OSB sheathing panel routed to a depth of 9mm to recieve oversized joist hangers.

suggested that the use of proprietary fixings may simplify the manufacture and assembly of a panellised component system.

Ladder beam type 02 has been designed with general fixings such as engineered joist hangers in mind, specifically, the width of the flange material has been designed to an assembled width of 60mm, a standard dimension for commonly available joist hangers. However there have been no trials of ladder beams in conjunction with fixings to test their compatibility. It is therefore intended that Bay 1 will test a number of alternative forms of proprietary fixings including face fixed hangers and top flange hangers.

FINDINGS

Two forms of joist hangers have been identified from the Simpson Strong Tie range as being appropriate for the application in combination with homegrown ladder beams, see figures 9.52 and 9.53. Both are single piece formed steel hangers designed for use with engineered I beams.

Although the Type 02 ladder beam has been designed with a 60mm standard width in mind, the depth of the ladder beam poses a conflict with the common available joist hanger depths. In the design of the panel system, the depth of the ladder beam has been determined by the depth of the primary structural frame, in this case a 210mm square hollow section. For the rural studio, this results in a ladder depth of 190mm in order for infill panels to overlap to one face of the primary structure and meet flush to the opposite face, see drawing ... This is in conflict with standard off-the-shelf joist hangers which are typically available in standard depths of 20mm increments in a range of 200-400mm. ‘Specials’ are available to order, however a price of nearly £10 per hanger made this option uneconomical. In order to incorporate hangers in the study, a 200mm deep joist hanger was therefore employed with a section of 9mm packing applied to the underside of the ladder to complete the depth. This resulted in one side of the sheathing board requiring an area of the panel to be routed out to accommodate this increased thickness, see figure 9.54.

Detailing a panel system to make use of proprietary fixings proved to be incredibly problematic. The design of the folded hangers employ 63mm steel shoulders, splayed to sit either side of the joist, whilst face fixed hangers have a 40mm folded back plate either side of the joist. Typically prefabricated panels would be designed with the structural elements, ie sole plates, studs and joists, situated at the immediate edge of the panel, providing support and enabling a direct connection to be made between neighbouring panels. However in order to allow the shoulders of each hanger of neighbouring panels to sit against one another on the bearing timber, ladders were required to be inset from the board edge. Within the 110mm clear span between ladders, the sheathing boards of neighbouring

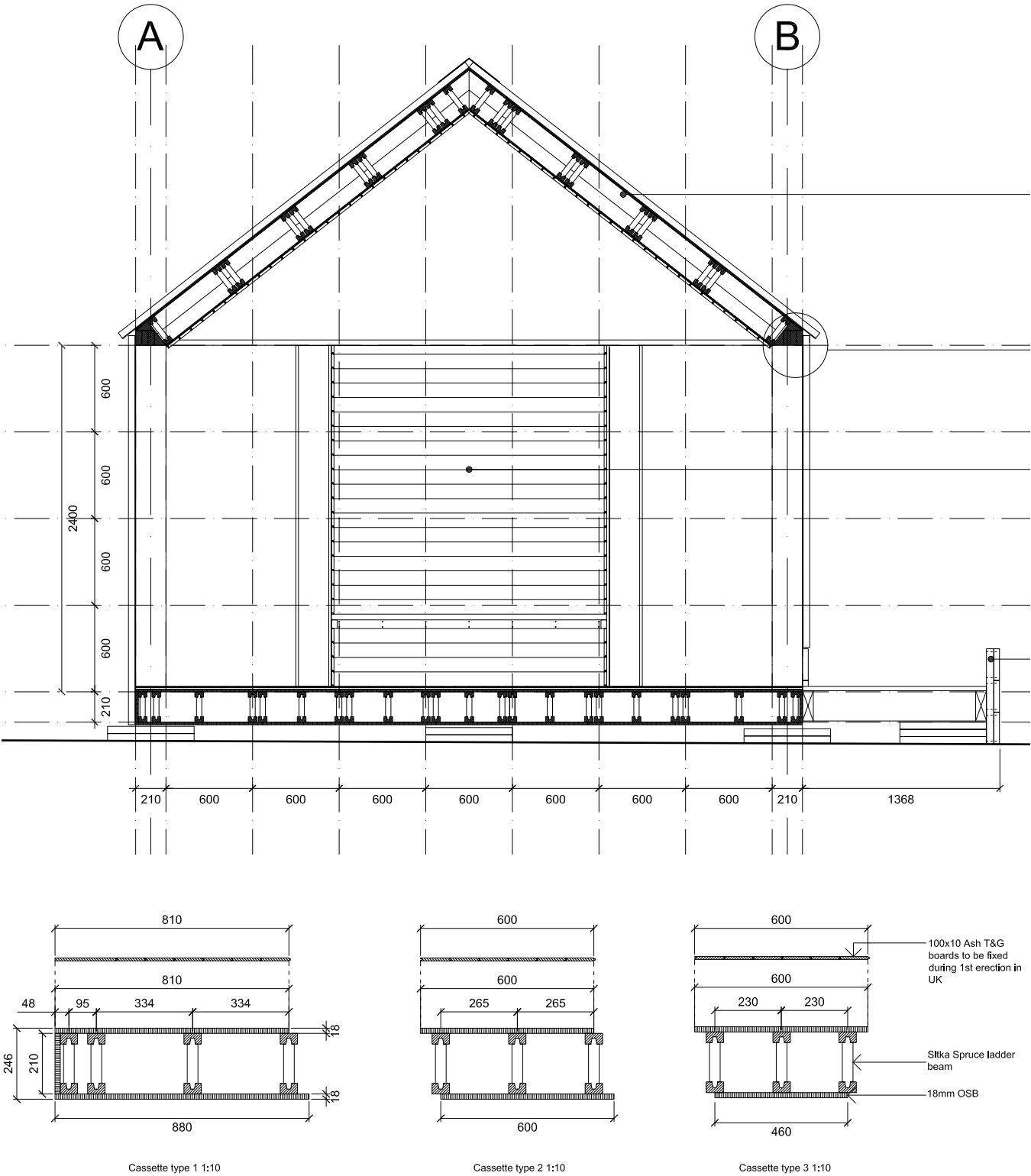


Figure 9.55: Arrangement of over lapping suspended floor panels for the Smithsonian Pavilion

panels must meet and provide capacity for a robust junction. A number of options for this arrangement will be trialled in Bay 1, including the provision of additional timbers fixed into the overhang section, to provide connection between panels.

In order to install the necessary fixings through face fixed joist hangers (IUSE) it is not possible to detail a closed panel system using these fixings types. However as fixings are installed through the top flange of ITSE joist hangers, it may be possible to enable access to fixing points within a closed panel system using these hanger types.

As ladders can not be detailed to the edge of the panel volume, it is very challenging to conceive a robust arrangement for the pre-installation of natural insulations into the panel during off-site fabrication.

9.05.6.3 BAY 2 - CLOSED PANEL SYSTEM

The Welsh Festival Pavilion trialled a closed panel system consisting of three panel types per bay. The proposed system of panels and the associated assembly process was significantly complicated by the intention to land sheathing panels on the ladder beams of neighbouring panels. In order for a wall or floor to act as a diaphragm plane, in typical open panel construction, the edges of sheathing boards are aligned to fall centrally on studs or joists, enabling neighbouring boards to directly fix into the same structural member. This arrangement ensures that all panel edges are propped and all loads are distributed evenly across structural beams. When replicated in prefabricated panels this results in a variety of panel geometries to allow panels to slot together with additional fixings installed on site to directly connect panels, see figure 9.55. The closed panels trialled in the construction of the pavilion had a number of successful details, most notably the ability for notched ladder beams to drop down onto a fixed bearing plate, however the number of different panels required and the need for a specific assembly order made the system over complicated.

It is therefore intended that Bay 2 will test the geometry of a closed panel system with the primary objectives being to;

- reduce the number of panel types required to improve manufacturing efficiency and standardisation, the construction process and interchangeability.
- improve coordination with a 600mm dimensional organisation to ensure greater material and manufacturing efficiency
- resolve issues related to connections made between panels and the post and beam frame to ensure panels can provide racking capacity
- consider the further advancement of prefabricated panels including the integration of insulation, windows and doors and services.



Figure 9.56: Notched ladder beam and timber bearing plate detail employed for the Welsh Pavilion.



Figure 9.57: Infill panels with notched ladder beam detail awaiting assembly for the Welsh Pavilion.

FINDINGS

The Welsh pavilion makes use of a notched ladder detail which enables the panel and ladders to be supported and fixed to a solid timber 'plate', which is fixed directly into the primary structure. This proved to be very useful as it provided a simple and robust structure that allowed the weight of panels to be safely supported and assembled prior to fixings being installed

The notched ladder detail employed was relatively easy to accommodate using the Type 01 ladder beam as both the flange and web consisted of substantial solid timber sections that could be efficiently trimmed to a suitable geometry. This however was not the case with the Type 02 ladder beam which relies on smaller sections of timber nail laminated together. A number of characteristics of the ladder geometry made the replication of these details challenging;

- the 60mm laminated flange material provides a much poorer fixing capacity for screws fixed through the sheathing, particularly if neighbouring boards are designed to meet centrally on one 60mm flange.
- the small section timber employed for web timbers does not have the bearing capacity provided by the large section C16 used for Type 01 ladders therefore it is not possible to notch into web timbers in the same manner
- as flange timbers are nail laminated the area of free timber for installing fixings is extremely limited

On discussion with the structural engineer it became evident that a number of design factors needed to be resolved in order for the objectives to be met;

In order to provide a diaphragm connection without resulting in the overlap of sheathings beyond the dimensional grid, a suitable connection needs to be integrated into the panel geometry to enable panels to be suitably fixed directly into the post and beam frame or to an additional member such as a sole or head plate which is suitably fixed directly into the primary structure. Most critical to this option is the design of junctions between ladder beams and solid timber plates, to ensure that loads can be transferred successfully within the panel geometry. In this context Burroughs advise that within the Eurocode calculation methods most determining to this design is the restricting specification placed on fixings being made into the end grain of structural members, which determines the number, and critically, the distance between fixings.

When considering the connection between adjacent panels, the structural requirements are significantly lower than diaphragm connections. As ladder beams and sheathing boards have been tested and applied within permissible spans, the panel as a single independent unit is capable of spanning within its given design limits. Combining two panels together and joining them appropriately

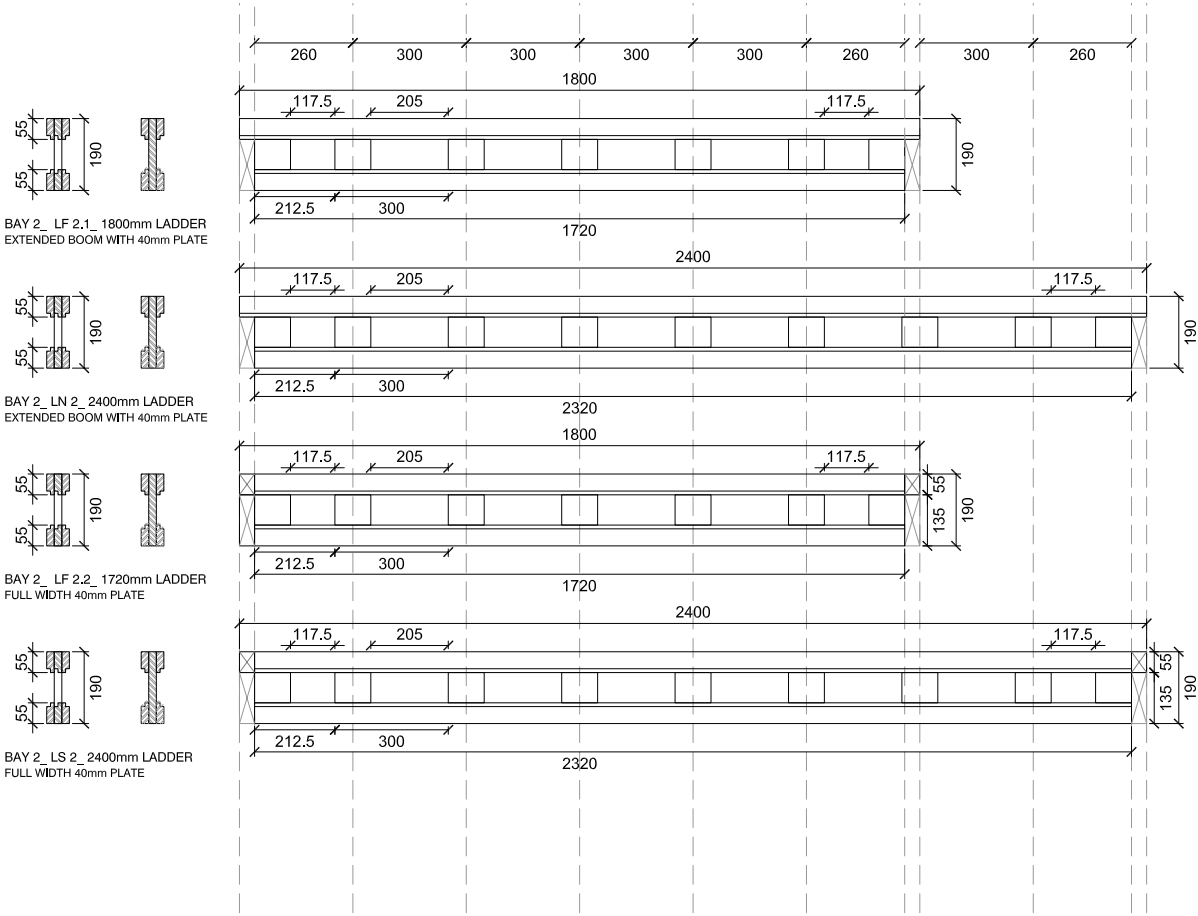


Figure 9.58: Alternative notched and plated ladder beam geometries for use in a closed panel system

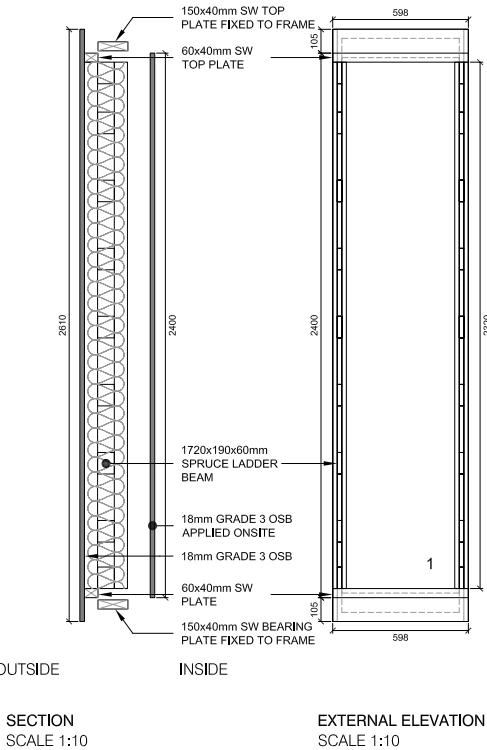


Figure 9.59: Type 02 Infill Panels for the North wall of Bay 2 with a square end ladder beam with panel plate fixed into the end grain of the external boom.

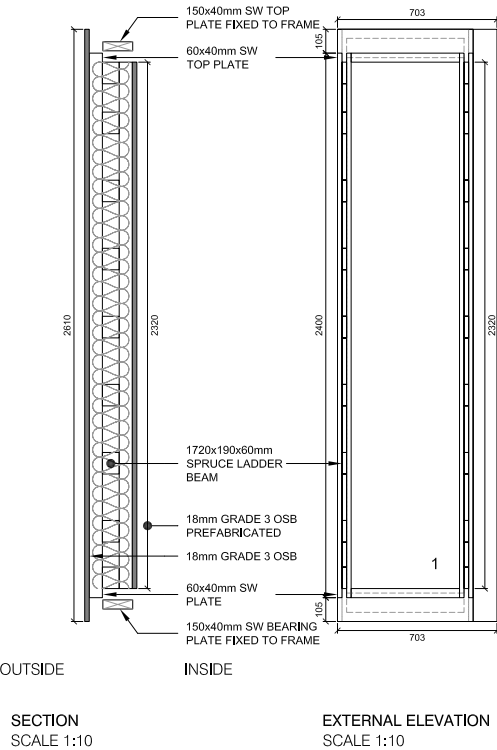


Figure 9.60: Type 01 Infill Panels for the South wall of Bay 2 with a notched ladder beam with panel plate spanning between the extended external boom.

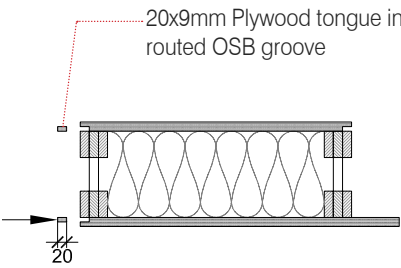


Figure 9.61: Loose tongue and groove junction to connect adjacent infill panels.

will improve the capacity of the combined structure however this is not factored into the structural performance. Therefore the critical aspect of this connection is to ensure that all panels are located with a good level of accuracy, and are capable of reacting to loading in a singular manner. If neighbouring panels are insufficiently connected and disproportionately loaded then it is likely that defects such as damage to finishes will occur. The simplest method of providing a direct connection, which is most commonly used in timber frame panel construction, is to provide a direct fixing between neighbouring structural elements. This however can not be suitably achieved as panels are closed and it is not possible to gain easy access to structural elements to install this type of fixing.

RESOLVED DESIGN

In general, all panels take the same format, with an internal and external sheathing of 18mm separated by two Type 02 ladders positioned at each edge of the panel. A number of geometries are trialled to provide a 'notched' ladder beam, which has capacity to make a direct connection with a plate fixed into the primary structure. These include the use of a notched sheet material to provide the web to the end section of each ladder see fig 9.60, and a full width panel plate fixed into the end grain of the top flange of each ladder, see fig 9.59. Also see drawings AC(2)102, AC(2)204, AC(2)402 and AC(2)502.

The closed panel system takes an alternative approach to providing a diaphragm type connection between panels and the primary structure. Rather than external sheathings overlapping the exterior of the primary structure, panels are designed to fit within the primary structure and therefore enjoy the benefits of designing to a rigid 600mm dimensional grid. In order to achieve this, solid section timber plates are prefabricated into the end of each panel, directly connected to the ladder beam and external sheathing material, and a bearing timber or plate is fixed directly to the primary structure. It is then intended that these two solid timber sections will come into contact through the assembly process, enabling fixings to pass through the external sheathing and panel plate into the bearing plate or wall plate. If specified correctly it is believed that this arrangement of fixing could act as a diaphragm panel and negate the need to overlap the frame with an external sheathing material to enable a direct fixing.

In order to improve the standardisation, interchangeability and material efficiency of panels, the proposed closed panel design does not employ sheathing boards to overlap the ladders of neighbouring panels. Alternatively, a detail is proposed which allows the introduction of a connector between panels, see figure 9.61. Designed as a loose element, in this case a length of 9mm plywood, the connector can be fixed into a profiled groove in each panel edge to create a 'male' connection to each panel where desired. This allows a standard panel to become scenario specific, ie around openings, without requiring the manufacture

of a new panel type. The specification of this connector needs further input from structural engineers to determine the capacity of alternative options, however as a concept it will be tested through the construction of Bay 2.

9.05.6.4 BAY 3 - OPEN PANEL SYSTEMS AND ALTERNATIVE SHEATHING METHODS

The majority of timber frame construction makes use of relatively simply detailed open panel systems, with insulations and services installed onsite prior to the installation of internal finishes, and membranes. The open nature of the panels allow access to the main structural elements enabling connections to be simply designed and installed from within the interior of the panel through solid section studs, beams and plates. This approach was applied to the design of panels for the Welsh Passive House.

In Bay 3, a simple system of open panels, consisting an external sheathing board with structural ladder beams, will be combined with alternative arrangements of panel plates in order to resolve an efficient detailed design for an open panel which has capacity to act as a diaphragm panel. Of primary concern to this analysis is the thermal efficiency and the manufacturing efficiency of alternative plate geometries as thermal bridging, including through solid timber members, is becoming an increasingly important design factor for high performance thermal envelopes.

Sheathing materials have proved a considerable challenge throughout the design of the system due to the limitations of readily available materials such as OSB and plywood. By withdrawing the need to provide a suitable structural solution to diaphragm action, infill panels become simply spanning thermal elements with reduced demands on sheathing materials. It is therefore proposed that this might enable an opportunity to replace panel type sheathing products such as OSB with a laminated or jointed sheathing product manufactured from small sections of homegrown timber, such as tongue and groove boards.

Prototyping of alternative panel types discussed in Section 6.03 showed some promise but did not fully resolve the detailing of panel types and most critically, the jointing between ladders and sheathing materials to ensure a suitable rigidity to loading. In the design of 3m spanning panels for the floor and roof of Bay 3, a number of arrangements will be proposed to consider the performance of a homegrown timber based panel and the related manufacturing efficiency.



Figure 9.62: Damp cellulose insulation blown into an open timber frame panel

Source : <<http://www.warmcel.co.uk/>>



Figure 9.63: Cellulose insulation blown into the closed cavity of a timber frame panel using a purpose made installation hose and nozzle.

Source : <<http://www.warmcel.co.uk/>>

9.05.7 DETAILED DESIGN : THERMAL ENVELOPE

The research proposal set forth the objectives to be both locally sourced and sustainable. By its nature this has subsequently focused on the application of homegrown timber however it is proposed that this objective should extend beyond the primary structural elements to apply to a whole system approach. The integration and use of natural insulations such as recycled newspaper, sheep's wool and hemp, in conjunction with the system components, has subsequently been a continued theme throughout the study. Through the development of Prototypical Studies and trials, Warmcel has emerged as the most applicable product type for this application.

Due to the nature of cellulose type insulations they are installed by one of two methods; they are either blown damp against an open panel and levelled off to stud depth or they are injected into a closed void as a dry powder. In both cases the loose fibres require containment in the form of building papers or panel type materials.

In discussion with Pen Y Coed Warmcel there would appear to be very few concerns or unique processes associated with combining cellulose insulations with a panel based system using either of the methods described above. In the case of injected insulation, it is likely that the each spacing between studs would need to be infilled independently to ensure that no voids occur. This is standard practice and is typically performed by preparing a circular opening within each panel suitable to receive the injection nozzle.

Regardless of whether insulations are installed on site or during the prefabrication of panels the resultant general arrangement of the proposed thermal envelope will be the same. An infill panel consisting of internal and external sheathing boards separated by a ladder beam or stud structure, with an overall depth of 230mm will contain a maximum Warmcel thickness of 190mm installed to the manufacturer's recommended densities. This arrangement is detailed in drawings AA(0)111 - AA(0)119.

The arrangement is detailed with a lightweight cladding to the exterior, in this case timber, and to the interior a 25mm service zone is formed between the structural envelope and the internal finishes and includes a 25mm layer of rigid insulation. An airtightness membrane and vapour control layer is applied directly to the Ty Unnos components to the exterior of the service zone. Applied successfully to the Welsh Passive House, this arrangement should ensure that there is a minimal need to break through the membrane whilst distributing services and it is unnecessary to integrate additional specialist seals into the design of panels to improve the airtightness of the proposed system of components.

BuildDesk U has been employed to replicate the general arrangement proposed

in the studio. An attempt has been made to make allowance for thermal bridging generated by ladder beams at 300mm centres however for ease of modelling solid section timbers have been employed. Detailed calculations can be found in Appendix C1. Table 9.5 shows the proposed U values calculated using this method.

FINDINGS

In comparison with the performance specification proposed in Section 5.07, calculated U values show that the external wall and suspended ground floor values are at the top end of the performance range however the pitched roof U value is currently outside the range proposed in the specification. In all cases however U values are within the advised limits provided by Building Regulations.

It is necessary to assume that these values are likely to be generous as the calculations do not accurately take into account the effects of thermal bridging generated by the post and beam frame.

It is interesting to consider the Heat Capacity given within each calculation. These figures highlight the concern that is associated with all timber frame constructions as they are considerably lower than those associated with other forms of construction. In some circumstances it may be necessary to look at methods of increasing thermal mass such as higher density sheathing boards and finishes, or the replacement of the suspended timber floor with a concrete raft.

9.05.8 DETAILED DESIGN : OPENINGS

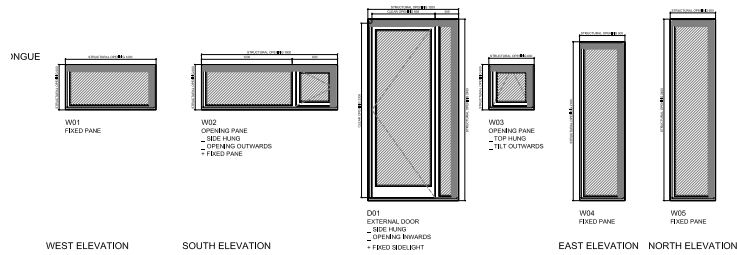
Drawings AC(0)110B - AC(0)116 show the proposed design of openings. As each opening is formed within differently detailed panel types, each has been considered individually. In addition to considering the fixing of windows, the design of openings has also had to take into account;

- The provision of a robust window surround which can fulfil any required structural function in the transfer of loadings around openings.
- The formation of a dimensionally accurate and stable structural opening to receive off the shelf windows, to be fixed at any desired position in the wall depth.

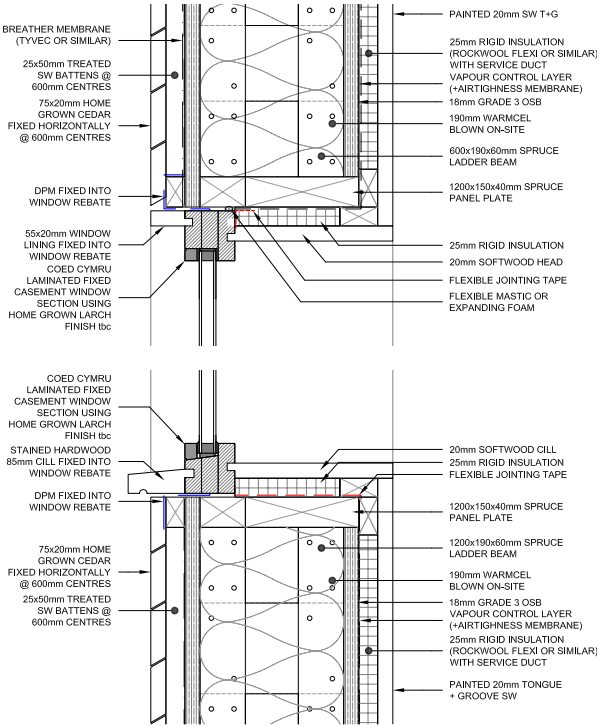
Table 9.5: Calculated U Values for proposed construction elements.

Component	Description	U Value W/(m²k)	Thermal Resistance R _t - m²K/W	Heat Capacity kJ/(m²K)
Suspended Ground Floor	230mm Infill Panel with Warmcell Insulation	0.13	6.91	23.40
Standard External Wall	230mm Infill Panel with Warmcell Insulation	0.19	5.16	10.10
Standard Pitched Roof	230mm Infill Panel with Warmcell Insulation	0.20	4.94	10.50

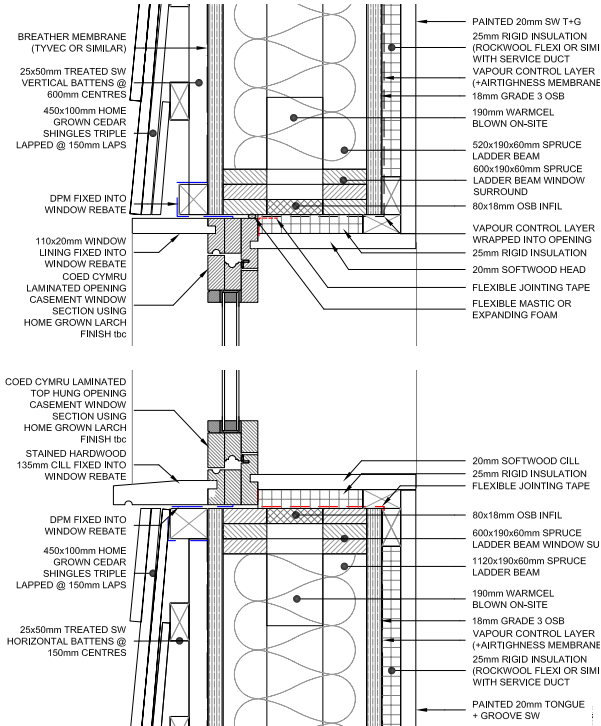
Figure 9.64: Window schedule of alternative opening types



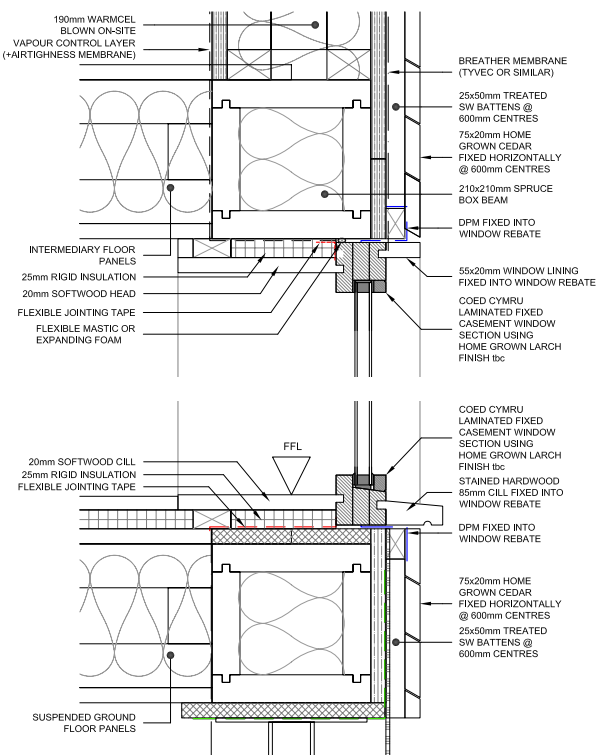
a) Proposed arrangement Window 01 and 02



b) Proposed arrangement Window 03



c) Proposed arrangement Window 04



d) Proposed arrangement Window 05

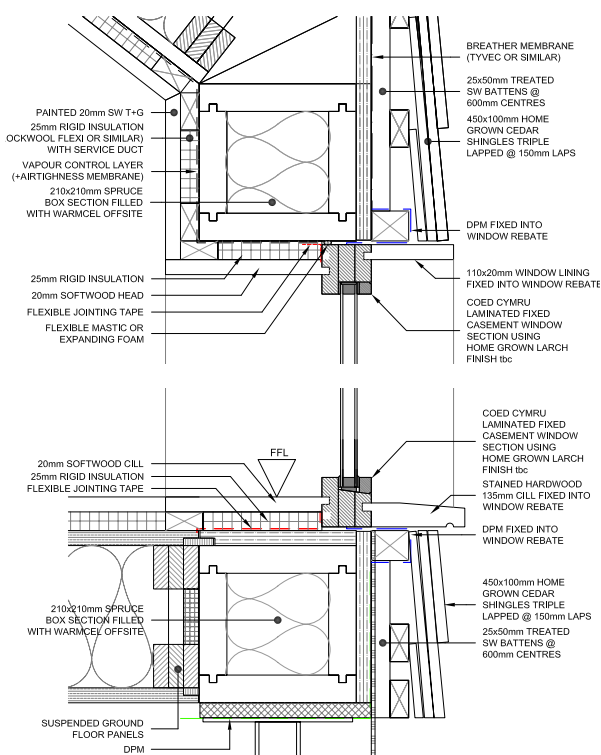


Figure 9.65: Exploded section of proposed prefabricated window cassette

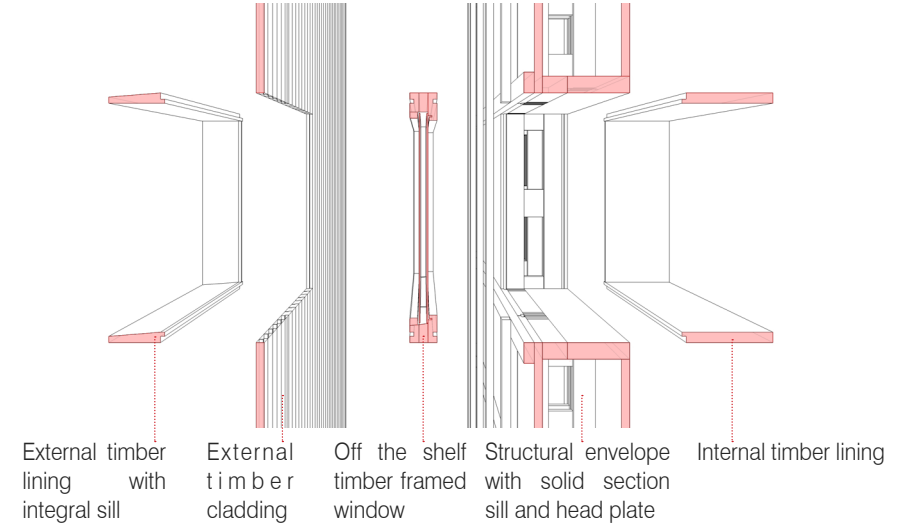
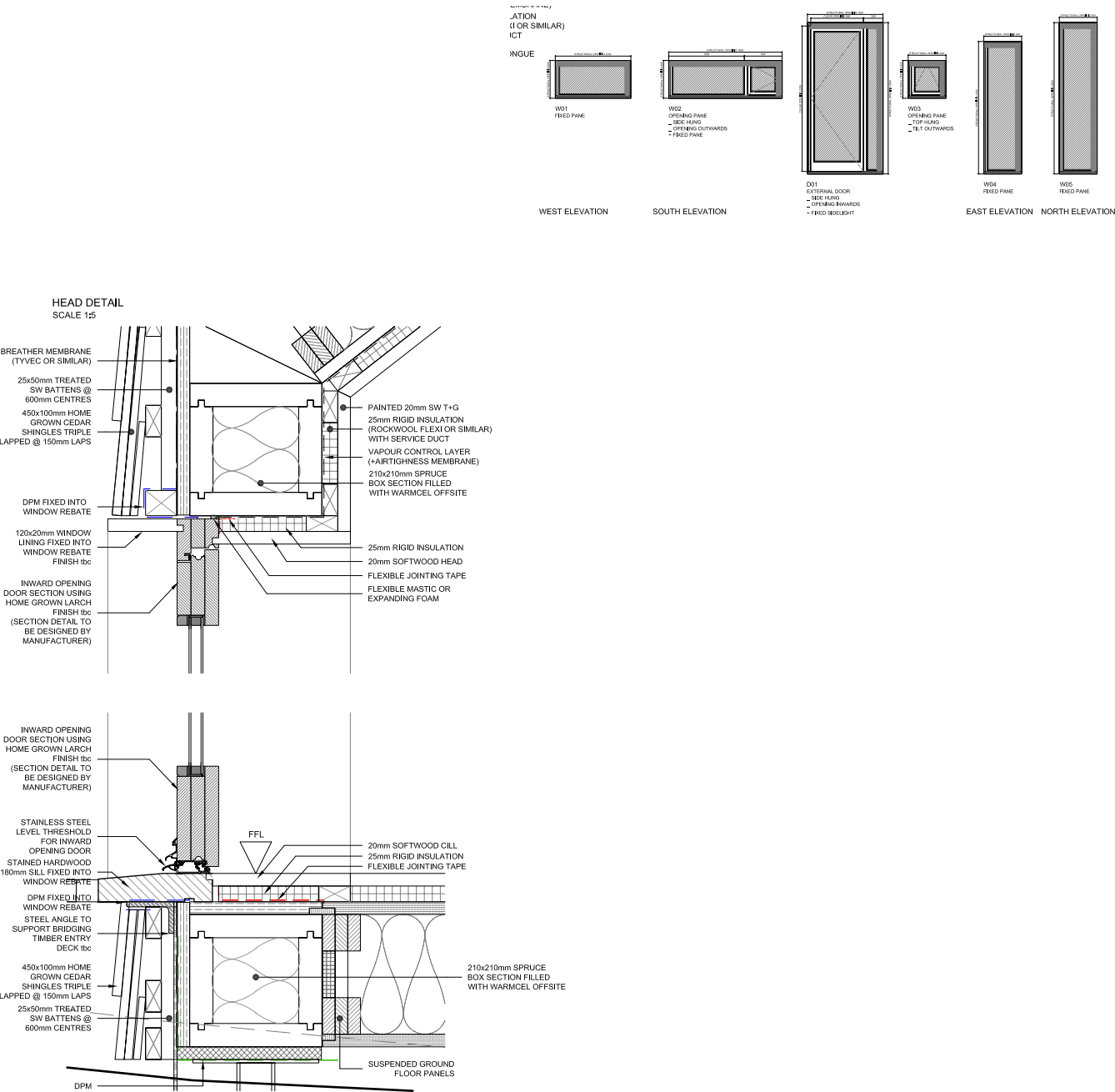


Figure 9.66: Proposed arrangement of Door 01.



position of window frame.

When considering the design of the opening surrounds, a number of recurring factors were identified as potentially limiting or compromising window design and installation;

Where panels are designed with sheathings overlapping beyond the dimensional grid in order to enable connection with neighbouring ladder beams, ie Bay 6 of the south elevation, sheathing panels to one side of the opening will extend beyond the structural opening. This is a further limitation associated with overlapping panels and demands either adjustment on site, or the fabrication of bespoke panels at openings.

The nature of the ladder beam structure results in a material void to the centre of the panel depth. In order to enable windows to be installed at any desired depth within the thermal envelope, the structural opening must be detailed to provide a robust structure to this full depth whilst maintaining an appropriately detailed thermal envelope. This is of particular concern where ladder beams are employed to provide the opening lining.

DOOR OPENINGS

During the development of Prototypical Studies and test assemblies a conflict emerged over the design of external door thresholds. Of primary concern is the combination of a level threshold detail with the ability to maintain a flexible approach to internal floor finishes and a need to ensure suitable weather proofing and sill externally.

The studio will employ an alternative approach to this detail with the inclusion of a floating floor deck, constructed on top of the structural infill panel deck, either on site or as an integrated element of the prefabricated panel. The floating floor is essentially an extension of the service void applied to all other surfaces of the construction. The addition of this floating floor enables the floor finish to be disassociated from the structural door opening allowing a much greater level of flexibility for framing and weatherproofing the opening. For example, figure 9.66 shows a standard sill installed within the structural opening, without requiring adjustment of the primary ground floor structure below the opening. The floating floor depth can subsequently be adjusted to suit the requirements of the construction, providing additional depth for services such as underfloor heating or enabling a thermally massive floor finish such as stone slabs, whilst maintaining a level threshold detail.

In addition to ensuring a greater level of flexibility and adaptability, the use of a floating floor internally and the inclusion of a solid section sill will also enable the design of a fully framed door component as a prefabricated module.



Figure 9.67: The Cedar House, a shingle clad rural dwelling in Norfolk by Hudson Architects
Source : <http://www.hudsonarchitects.co.uk/>

9.05.9 DETAILED DESIGN : FINISHES + SERVICES

The integration of services into a system build has formed an ongoing discussion throughout the development of the research study. In order to reduce onsite construction tasks, advanced panel systems are increasingly integrating plug and play service systems. This can significantly reduce build times, on site working and waste if effectively integrated, however the systems and manufacturing processes involved are usually highly skilled and expensive. At the other end of the spectrum however is the use of a simply fabricated open panel system which allows access for the installation of first fix on site. This results in a more traditional construction process with a much higher level of on site work.

The construction of the Welsh Passive House successfully demonstrated a median option in the form an integrated service zone to the interior face of the prefabricated thermal envelope. The Passive House introduced a number of additional onsite tasks in order to realise this detail including the onsite application of an airtightness membrane, battening and following first fix, wood fibre insulations. The Rural Studio will adopt this arrangement as a resolved solution and during the manufacture and assembly of panels, consider the furthering of panel designs to incorporate more of these additional tasks into an advanced prefabricated panel.

It is unlikely that it is within the scope of the Studio project to fully test the efficiency of these additional manufacturing processes. However the benefit of this proposed design is that services can be installed at any point without effecting the structural envelope of the building therefore connections to services are to be installed to the building with the intention of completing this work at a later date.

To the exterior of the thermal envelope a light weight cladding of homegrown cedar shingles and horizontally fixed heat treated softwood will be applied on battens and counter battens directly fixed into the sheathing of the panel system. The design of external cladding is not particularly influenced by the specification of the homegrown timber system. The provision of an 18mm sheathing panel to the exterior of the structure ensures that most cladding options can be tied into the system.



a) Select 2 lengths of standard C16 Sitka Spruce 225 x 47mm for flange timbers and 2 lengths of 150 x 47mm for web timbers.



b) Plane and mould web timber to give a section of 150 x 40mm with tapered tongues to each long edge.



c) Plane and mould the flange timber to give 2 sections of 210 x 40mm with 2 longitudinal grooves.



d) Working immediately adjacent to the press on an extended table, polyurethane glue is applied to the prepared grooves in the bottom flange.



e) Web timbers are dropped into the profiled grooves.



f) The tongue and groove profile holds the assembled box stable and square during assembly. Adhesive is then applied to the upper edge.



g) The upper flange is located onto the tongues of the web timber and the assembled box pushed into the press, against rear uprights.



h) Filling the hose line with air using a small industrial compressor lifts the table bed and compresses the box against the top restraints of the presses. Clamps to the rear uprights ensure the section is square.



i) Once cured remove from press, remove excess glue and trim box section to length.

9.06 MANUFACTURE

9.06.1 MANUFACTURE : PRIMARY STRUCTURE

The box section assembly process as described in Section 6.01.1 has remained essentially consistent throughout the project. Box beams were predominantly reused therefore there was little assembly required at this stage of the project, however a visit to Kenton Jones Joinery provided an opportunity to witness the assembly process and discuss any concerns over the assembly process with Kenton and the operatives. The primary concerns remained to be related to the glues used for manufacture. Due to somewhat frustrating licensing and translation reasons, the glues employed by KJJ are slower curing derivatives than those available for the application. This results in the cramping process requiring an extended curing time of up to 60 minutes per beam. In order to reduce the time spent in the jig, KJ has introduced screws to the joint which maintains compression during the curing time following an initial period spent in the press. KJ has also developed a secondary horizontal press which has capacity to receive up to four short length beams at any one time.

KJJ have worked closely with Pen Y Coed Warmcel to develop a process for the installation of Warmcel into the box section during the assembly process. Once cured and cut to length the beams are plugged and Warmcel blown into the full depth of the beam to a consistent density by steadily withdrawing the hose from the box section hollow.

As a number of the existing box beams were cut and mitred to alternative geometries, the assembly process did require the preparation of spanning edge beams to receive a 40mm shear plate connector to each end. This is typically achieved at KJJ using a large diameter circular mitre saw capable of cutting the full depth of the box section. In the absence of a suitable dimension mitre saw, this process was performed by hand as described in figure 9.65. This was an extremely inefficient process due to the geometry and quantity of these junctions.

PREVIOUS PAGE

Figure 9.68: Assembly sequence of Sitka Spruce box section using the pneumatic press at Kenton Jones Joinery.

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Figure 9.69: Alteration of mitred columns for reuse as spanning edge beams.

- a) The Mitred columns are first marked up and trimmed to a square edge using a plywood jig.
- b) Using a circular saw and hand saw, the box beam is cut to the centre line of the beam web.
- c) The beam is then cut with the end grain to create a 40x105mm notch to receive the softwood shear plate.



9.06.2 MANUFACTURE : PRIMARY STRUCTURAL CONNECTORS

The steel and timber connectors were found to be oversized when trialled with the newly manufactured hollow box section columns. Initially designed to fit into a 210mm square section with webs and flanges planed to a 38mm finished thickness, the connectors were made to an overall size of approximately 130mm. More recent box sections however employ webs and flanges machined to a 40mm thickness giving a hollow of 130mm square which proved to small to receive the connectors. In addition the connectors were found to have swelled due to wetting whilst stored on site. Initially connectors were machined by hand using an electric plane however this proved to be a time consuming and inaccurate process. With each connector weighing nearly 30 kg, moving the connectors around and trying the connectors in place was challenging. Connectors would often stick on glue runs or timber swathes on the inside of the box section. The remaining connectors were therefore fully dismantled and passed through the thicknesser and planer to a revised dimension. The resultant accuracy of the planed and adjusted steel and timber connectors was questionable, as dimensional tolerances had to be much greater than those associated with the plywood connectors, in order to ease the handling of the heavy connectors into the box section hollow.

In order to reduce weight and ease assembly steel and timber eaves and ridge connectors were replaced with newly manufactured plywood and softwood connectors. In comparison the manufacture of these connectors from raw proved to considerably more straightforward, taking approximately one hour per connector and achieving an accuracy of approximately $\pm 2^\circ$. Prepared predominantly using the table saw, a good level of repetition and accuracy could be achieved once initially set up to the correct angles and dimensions.

PREVIOUS PAGE

Figure 9.70: Assembly sequence of steel and timber hybrid bolt laminated connector.

Figure 9.71: Assembly sequence of plywood and timber glue laminated connector.

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Figure 9.72: Preparing steel and timber connector to install into eaves junction.

Figure 9.73: Machining timber cheeks by hand to fit box section hollow.

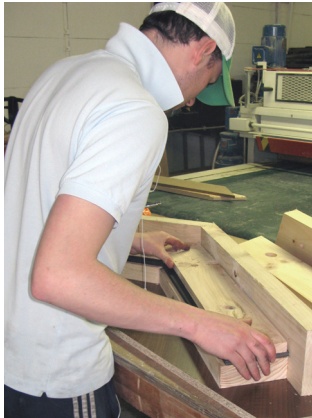
Figure 9.74: Sliding connector into box section hollow.



a) 150x50mm Sitka Spruce is planed on all four sides and trimmed to length and angle using a mitre saw.



b) Timber 'cheek's are predrilled, first with a 16mm drill, then a 30mm augur to accommodate the nut and bolt head within the timber section.



c) Using an assembled jig set at the desired angle, assemble laminates including steel plates and timber cheeks.



d) Once located tap through 4 no M16 bolts and washers, turn over and apply washers and nuts.



a) Blocks and plywood pieces are clamped to a sheet of plywood to create an assembly jig



b) The first layer of plywood is used as a template to set out the jig. A layer of Polyurethane glue is applied to the plywood and the mitred timber laminates are pressed firmly into place



c) Glue is spread across the timber layer and a further lamination of plywood pressed in place.



d) A second lamination of mitred timber and plywood are glued in place to complete the connector.



e) Clamps are applied to press laminations during curing and ensure no slippage occurs.



f) Whilst clamped pilot holes are drilled and 4 no 80mm screws driven through the laminations. Once cured, the clamps are removed and a further 3 screws driven in from the opposite face.



a) The table guard is set to 55mm and a timber spring is clamped to the table base to exert pressure on the timber section. A roller stand supports the timber section.



b) Timber section is ripped at 55mm and received by a roller stand on exit. The timber spring ensures that the timber is pressed firmly against the guard throughout its length with the operator inserting the timber and receiving the timber at the other end. The 55mm timber section is stacked ready for trimming to length.



c) The remaining section is stacked separately and returned to the saw when the timber spring has been adjusted to exert a closer pressure on the narrower timber section.



d) The second pass removes the excess of the half lap profile ensuring both sections are 55mm wide with a tolerance of $\pm 1\text{mm}$.

Figure 9.75: Ripping half lap 125x20mm boards to give two 55x20mm timber sections for use as boom timber



Figure 9.76: Cutting boom timber to length using a mitre saw. A timber measuring stick with end stop is used as a length gauge.

9.06.3 MANUFACTURE : SECONDARY STRUCTURAL LADDER BEAM

PREPARATION OF TIMBER COMPONENTS

Due to the available raw material, a number of additional processes were required to prepare material for the ladder beam assembly. Typically standard sections of 60x20mm and 100x20mm would be employed for the construction of booms and webs respectively. In order to prepare suitable sections for these purposes the halflap profiled 125x20mm softwood was ripped into two sections of 55x20mm for boom timbers and 95x20mm for web timbers. These additional operations are demonstrated in figures 9.75 and 9.76. Approximately 60-70 sections could be prepared for boom timbers in 2 hours, providing enough material for 15 to 18 beams.

Once cut to section, boom timbers were then selected against Doc 2187- Ty Unnos Ladder Beam Timber Specification produced by Burroughs. This specifies that material with full depth fissures or knots in excess of 50% of the timber face are to be rejected.⁶ Employing this specification a reflective sample of 80 sections of 3.0m were selected for permissible boom timber lengths resulting in;

- 37 lengths of 3m
- 29 lengths of 1.8 - 2.4m
- 14 lengths of ≤ 1.2 m

The percentage of timber appropriate for longer timber lengths was worryingly low due to the quantity of large knots in the timber sample. Larger knots tended to be associated with larch boards contained within the sample. In comparison Sitka spruce samples typically displayed a larger number of knots, in particular dead knots, but of much smaller dimensions.

Boom timbers were subsequently cut to length on the mitre saw using visual selection to maximise permissible lengths. A fixed end stop and measuring stick ensured repeated lengths could be cut without re measurement. Between 30 and 40 booms could be prepared in one hour.

All rejected timber and timber off cuts were subsequently recycled for the preparation of infill boom timbers. Using a mitre saw and fixed end stop, set up using a number of templates, timber lengths are cut to a number of fixed lengths determined by web spacings. In most cases ladders employ two dimensions of boom infills, a 205mm standard infill, and a 120mm infill for the endmost spacing. This repetition makes the preparation of timber components very efficient with approximately 100 infill pieces cut an hour on a mitre saw and potentially double this on a table saw.

6 Burroughs, *Doc 2187- Ty Unnos Ladder Beam Timber Specification* (Cardiff: Burroughs, 2009) p. 4.

This process is repeated for the production of web timbers to a standard 190mm length. Web timbers must also adhere to the timber specification, written by Burroughs, therefore web timbers are defect cut to remove rejected material, resulting in a higher production of waste material and a reduction to 90 web timbers cut an hour, equivalent to nine 3m ladder beams.

Once the timber is prepared and ready for assembly, full length booms are stuck and stuck under cover. Due to the high moisture content of the raw material it became necessary to weight the cut timber as there was a relatively high frequency of twisting of the cut lengths. Once cut to length however and pressed into the ladder jig there were very few cases of material being rejected.

LADDER ASSEMBLY

The proposed ladder beam jig included a number of adjustable and / or movable parts to allow the assembly of multiple depths of ladder beam using the same set up. During manufacture and assembly, these elements were removed from the proposal and replaced with a fixed rail, setting the depth of ladder at 190mm. Although movable parts would enable multiple depths to be manufactured without significant alteration, or potentially enable a release mechanism to ease the removal of the assembled ladder, in order to ensure accuracy and ease use, movable parts require significant design consideration, potentially employing complex mechanisms. A further iteration of this jig should consider this in further detail, however as a fixed ladder depth is used throughout it was not deemed within the scope of this study.

An initial trial found that the arrangement of fixed steel angles and hardwood stops ensured an accurately manufactured ladder beam. However with all of the elements fixed to the steel bed, the ladder once assembled was very difficult to remove from the jig. In place of moving parts, a simple solution was employed, by fixing the hardwood stops to a backing board of thin plywood instead of to the jig base, the fixed ladder was found to lever easily out of the jig. In addition a layer of beeswax applied to each surface of the jig significantly reduced friction.

The jig was employed to assemble a total of 144 ladders for the studio. In general ladders were manufactured to high level of accuracy, and with practice the manual assembly of components developed into an efficient manufacturing process. There are however a number of alterations, with varied levels of sophistication, that could be made to the set up if alternative ladder depths were required.

The assembly of ladder beams was initially slow with 2.4m ladders taking 10-12 minutes to assemble, nail and remove from the jig. Once practiced however this time was reduced, with 3.0m ladders taking 6-8 minutes to complete. This assembly time was particularly aided by the upgrading of a small 25l compressor to a larger 50l compressor with capacity to continuously nail the full length of a



Figure 9.77: A solid timber plate is inserted into the jig to set out the geometry of a notched ladder beam formed with;
a) an extended top boom and inset end web.
b) a notched plywood end section reinforcing an extended top boom.



a) The jig is prepared with oak separator blocks in place and cut timbers placed around the table. Table must be clear of timber chippings and dead knots.



b) Place boom timbers into the jig and tap down flat against steel table and against end stop, oak spacers ensure booms are tight against steel rails.



c) Insert web timbers into the jig and tap down flat against boom timbers, oak spacers act as a guide to web spacings and right angle.



d) Insert boom infill timbers between webs, the first web spacing is reduced to set out the remaining webs at 300mm centres.



e) Place boom timbers into jig, half lap edges face into the centre of the ladder. Tap against table and end stop to ensure tight fit, cut booms act as a length gauge for accuracy.



f) Starting at the open end nail through boom timbers at a slight angle into steel table to crimp nails. Pneumatic nail gun is held with a relaxed arm and nails fired to the drawing pattern as shown in dwg...



g) Ladders are then tidied up manually to ensure that nail heads and crimped ends are suitably bedded into timber, particularly where nails have 'bounced back' off table.



h) Remove ladder from jig using a claw hammer and remove oak spacers from between the webs. Store flat in a dry place.

Figure 9.78: Assembly sequence of nail laminated ladder beam.

3m beam without witnessing a significant drop in pressure.

The quality of manufacture was found to be significantly effected by the species of softwood occurring in alternative positions in the laminated section. Larch was found to be particularly hard and brittle compared to samples of spruce and Douglas fir resulting in a greater resistance to nailing. Larch battens positioned as the lower booms in the jig would often result in a high number of nails 'bouncing' back from the timber. Splitting was relatively common in the end section of the ladder beam with each timber species, however splitting also occurred on nails driven into the centre of larch booms, often along grain between knots. Sitka spruce proved to be the most receptive of the softwood species to driven nails, with nails penetrating and crimping neatly. However nail heads could often penetrate the surface of the Sitka spruce booms to a depth up to 5mm, if driven at too high a pressure.



a) A jig is prepared using plywood fins and a box section. A ladder beam, prepared with joist hangers, is dropped into the plywood fin and pushed under the box section stop.



b) Place a second ladder into location. Plywood fins ensure ladders are set parallel and accurately centred.



c) Box section stop ensures ladders are set square to the OSB side rail.



d) A precut and routed OSB sheathing is prepared with a spruce board nailed to the long edge to provide connection with neighbouring panels.



e) Sheathing is turned over and positioned on ladders with routed grooves located over the oversized joist hangers.



f) Screws are installed at equal centres through the sheathing into the ladder boom.



g) A measuring tape is used to set out screw centres.



h) An adhesive seal is applied to the perimeter of the panel intended to compress against neighbouring panels and structure to improve airtightness.

Figure 9.79: Assembly sequence of open infill panels for Bay 1 using a manufacturing jig.

OPPOSITE PAGE

Figure 9.80: Plywood fins act as a restraint to ladder beams, locating them parallel and accurately centred to receive sheathing boards without measurement.

Figure 9.81: An offset of box section frame is employed as an end stop to the ladder beams, accurately set out perpendicularly to the side rails of the jig.

Figure 9.82: Close up of the notched sheathing board to receive the oversized joist hanger protrusion.



9.06.4 MANUFACTURE : SECONDARY STRUCTURAL INFILL PANELS

With all engineered components produced and sheathing boards cut, the assembly of infill panels was performed in increments as the primary structure of each bay was being constructed. As each bay and element of the structure explored a wide range of detailed studies, there was very limited repetition achieved during fabrication, with a maximum run of 4 panels for each type. Each new panel design would therefore be initially prototyped by hand, ie, set out, measured and fixed as loose elements based on manufacturing drawings. Recreating the manufacturing process using a former or jig would then be considered, using templates and setting out elements to ensure components are accurately supported and restrained during fixing. Typically this resulted in a significantly extended manufacturing program than would otherwise be expected. However the success of this time investment was immediately realised with the manufacture of each repeated unit getting progressively quicker.

The typical assembly method of panels for Bay 1, Bay 2 and Bay 3 can be seen in figures 9.79, 9.83-84 and 9.88 respectively. The following is a brief summary of the findings from each structural bay.

BAY 1

In order to accommodate the oversized joist hangers, sheathing boards had to be prepared with a rebated section using a router. This process was considerably time consuming, and makes the use of joist hangers entirely inefficient. It did however fortuitously provide a locator for the ladder beams in relation to the position of sheathing boards.

As identified by KJJ in the earlier Prototypical Studies, the accurate setting out of ladder beams in relation to the sheathing boards is a challenging process, due to their location inset by 100mm from the panel edge. With the manufacturing jig set up, checking the accuracy and squareness of their position prior to fixing was largely impossible, resulting in panels sitting skewed within the structural opening. The jig arrangement certainly eased the assembly process but the quality of fabricated panels was generally disappointing.

When installing 9mm OSB as a sheathing material, the sheet material was found to be generally excessively distorted. When fixed to ladder beams, this was slightly resolved, however the thin nature of the material and the lack of any additional lateral connection between ladder beams in the form of noggins or panel plates resulted in panels tending to follow the twist of the OSB material until fully restrained against the primary structure.

During manufacture, specified panel fixings were found to be problematic when driven into the flange material of Type 02 ladder beams. Predominately 35mm

Figure 9.83: Assembly of Type 01 closed panels with panel plates fixed between ladders.

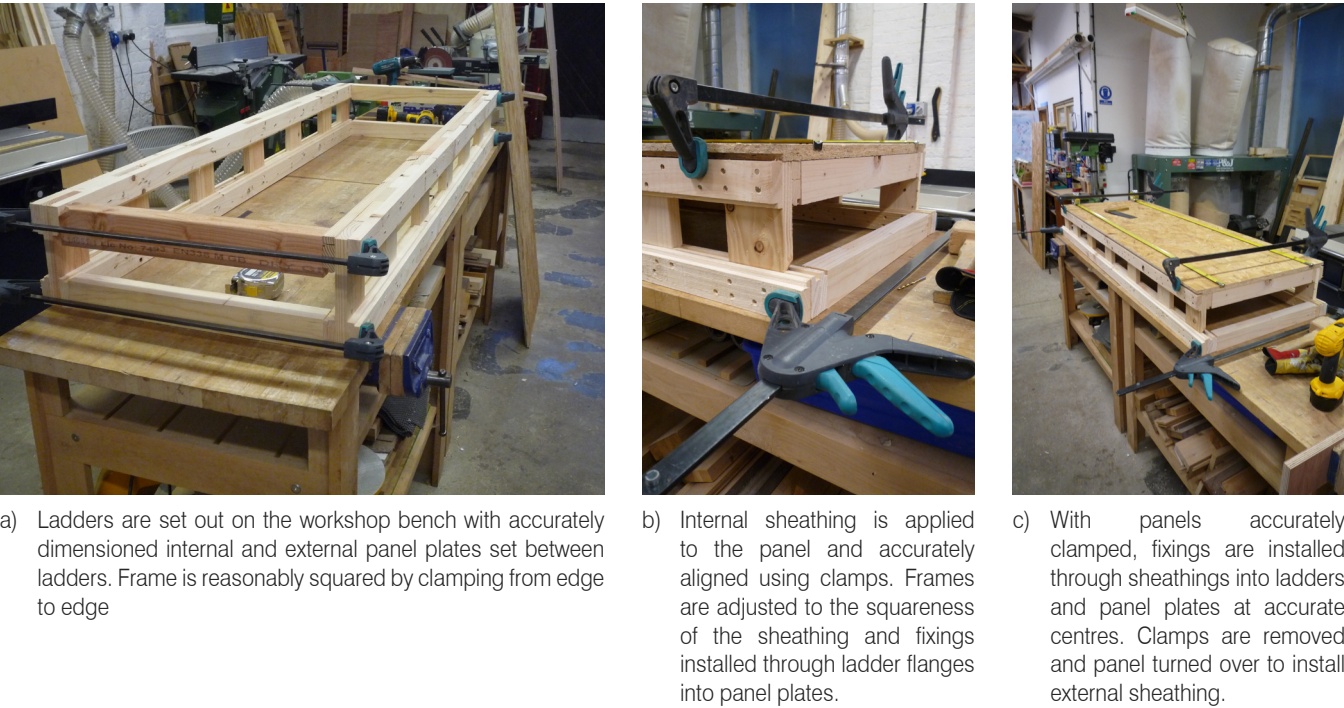


Figure 9.84: Assembly of Type 02 closed panels with panel plate fixed into the endgrain of ladder flange

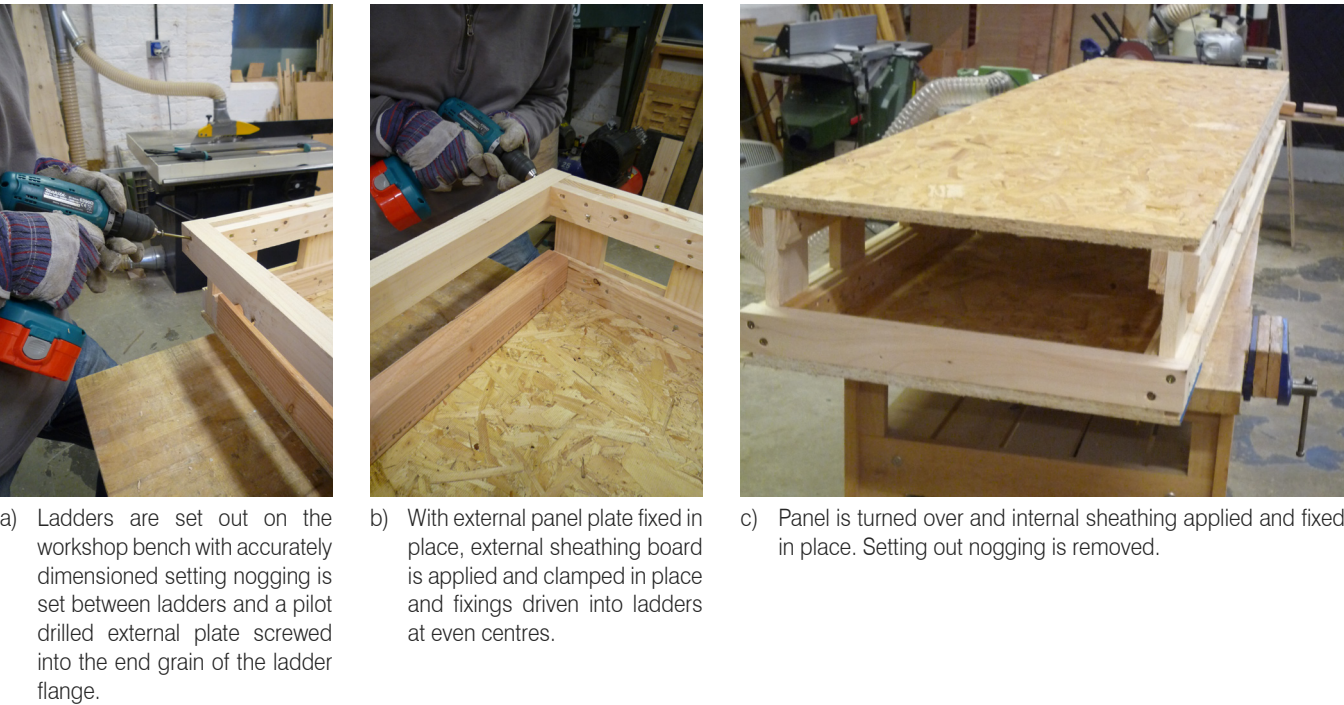


Figure 9.85: 18mm OSB sheathing boards are passed through a spindle moulder to route a 9mm groove to each long edge.



Figure 9.86: 9mm plywood tongues are inserted as a final operation immediately prior to installation on site.

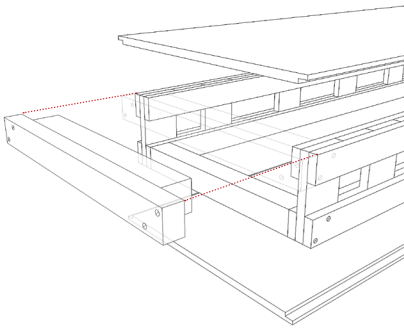


Figure 9.87: Laminated or solid spruce panel plate combining endgrain and side grain fixings.

fixings were found to not successfully bite into the flange material when driven through 18mm OSB. On discussion with the structural engineers, fixings were uprated to a minimum length of 50mm throughout, and generally this resulted in good connections.

BAY 2

Following assembly of a prototype closed panel, it was concluded that panels would be most efficiently manufactured without the use of a jig. The manufacturing process is shown in figures 9.83 and 9.84. The geometry of the closed panel system makes use of ladders and plates set up at the extremities of the panel, in line with external sheathings. As is common in traditional panel manufacture, the components can therefore be aligned using the sheathing as a guide, held in place using standard clamps and fixed together. As sheathing boards are fixed to both sides of the panel a rigid jig would inevitably limit access to the panel, and the efficiencies afforded by a jig would be negated by having to remove the panel to be able to complete processes.

The system employed a number of geometries for the integration of panel plates into the end of each panel, and in general all types were reasonably successful. Figures 9.83 and 9.84, show the two primary alternatives. Panel Type 01 proved to be the easiest to prefabricate into panel form as the panel plate could be simply clamped between the ladders prior to fixings being installed, and the plate could act as an accurate guide to the panel width. Panel Type 02 was harder as the plate could not be easily restrained whilst fixings were installed. A combination of the two systems whereby a notched or laminated plate as shown in figure 9.87 is therefore proposed as a positive compromise, combining the qualities of both plates whilst providing additional capacity for fixings to meet the Eurocode design requirements.

In order to integrate a loose tongue and groove junction, the long edges of each OSB sheet was routed with a 20mm wide groove to a 9mm depth. When fixed to the ladder this formed a three sided housing to recieve the loose plywood tongue. Although challenging with the machinery and facilities of the workshop due other size of boards, the routing of these joints proved to be an efficient and accurate process, which could be improved with dedicated machinery.

The relative simplicity of the manufacturing process made the transfer of instruction comparatively easy. Low skilled individuals were able to pick up the processes involved in the manufacture of the closed panels, and accurately and efficiently manufacture panels. As panels were formed using accurately prepared sheathing boards, quality control could be also easily assessed and maintained.



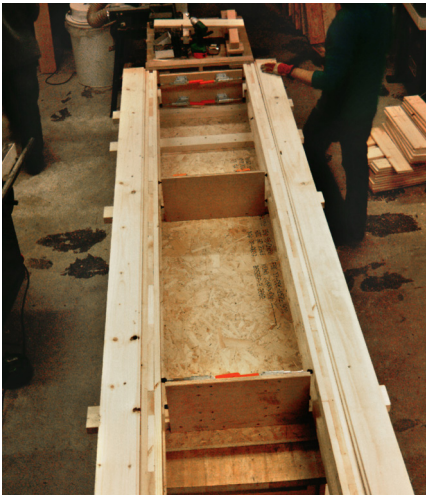
a) The jig is set up on the standard workshop benches comprising four plywood fins, notched to receive and restrain ladder beams.



b) Ladders are installed into the notched fins and pushed up against an end stop, to the far end of the photo. Fins are spaced to receive alternative ladder lengths.



c) With ladders in place, push clamps fixed to fins push ladders tight against the plywood retainers ensuring a parallel fixed width.



d) Spruce side rails are added in to the jig, fixed directly to the plywood fins to provide an accurate straight edge restraint for sheathing boards.



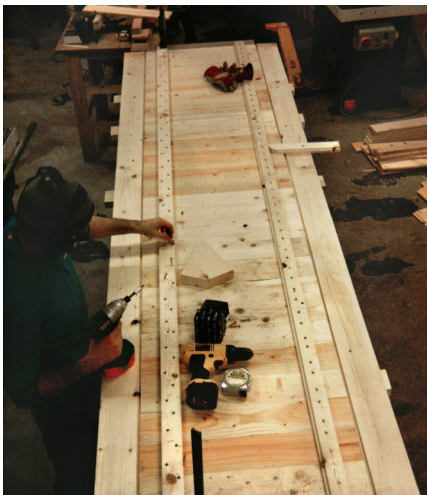
e) Cut to width and thickness, half lap spruce boards are slotted laterally into the jig, sitting on the top flange of the ladder beam.



f) Lateral spruce boards are double nailed to the ladder flange.



g) With open panel removed, the jig is employed to manufacture additional sheathing boards. Spruce half lap boards are set out in jig and longitudinal rails are located and clamped in place.



h) Using a pneumatic staple gun, rails are stapled to the spruce boards to produce a flexible but transportable sheathing panel.



i) Panel is removed from jig and located against ladders of the open panel using the longitudinal rails. Boards are subsequently screwed into the top flange of the ladder beam.

BAY 3

In the design of a jig for bay 3, a similar approach to that used in Bay 1 was proposed. However a system of push clamps and cams were applied to the plywood and timber framework to ensure a greater accuracy in the positioning of elements. See figure 9.88a. The realised jig required a number of additional assembly processes however the quality control and ease of assembly was noticeably improved. The jig is designed to a fixed panel width of 600mm, however it can receive any length of panel within the proposed 300mm to 3000mm range.

Figure 9.88 shows the assembly of an all spruce based panel. Two arrangements of half lap boards are used to realise an internal and external sheathing; longitudinal boards run the full length of the panel, fixed to a lateral substructure of noggins at even centres, and short lengths of lateral boards span from ladder to ladder. Although consisting of fewer components, panels based on longitudinal boards proved to be much less efficient to manufacture as material selection to give 6 appropriate 3m length boards resulted in significant rejected material, and the assembly of a robust substructure gave additional complexity.

In comparison lateral short boards could be easily sourced from the available material, with boards defect cut to provide 600mm lengths with minimal waste. As open panels, one face of the spruce panel is nail laminated directly into the ladder beam flange. Setting out is integrated into the jig design with fixed rails ensuring a reasonable straight edge. A loose panel is then made up using a set of longitudinal rails, simply nail laminated to each board. Although the panel remains very flexible for transport, it is dimensionally accurate and integrates with the open panel without adjustment.

The fabrication of spruce based panels highlighted a number of concerns with the quality and consistency of softwood falling boards. Half-lap boards were available for the project however a tongue and groove profiled board would have been much preferable in this context. It was found that there was significant variation in the thicknesses of the supplied boards, varying by up to 3-4mm. This resulted in an irregular surface finish which would cause conflict with finishes. Boards therefore unfortunately required additional processing using a thicknesser to achieve a consistent board section.

The open panel system designed for the north and south wall of Bay 3 trialled a number of alternative arrangements for panel plates. These are shown in Dwg AC(2)203. In all cases the arrangements provided a suitable connection between the panel and the primary structure however a number of observations can be reflected upon during assembly;

- Type 02 - Panel plate sits into the web section of each ladder, allowing fixings to be installed through the ladder flange without the need to fix

PREVIOUS PAGE

Figure 9.88: Assembly sequence of spruce sheathed infill panels for Bay 3 using a manufacturing jig.

into end grain. The geometry of the ladder to achieve this detail was more complex and the nail laminated section of the flange provided a poor fixing. As the plate is located centrally within the panel it is not possible to provide any lateral restraint to the internal and external sheathings however this does result in a reduction to thermal bridging.

- Type 03 - A full width and depth panel plate is fixed directly into the end grain of each ladder providing a fixing for both internal and external sheathings. Although concerns were raised about the quality of fixing into end grain, the capacity of these fixings appeared to be robust.
- Type 04 - Individual battens are fixed to each ladder flange using fixings driven into end grain timber. The solution provides a positive solution to thermal bridging, however manufacture is challenging as battens are difficult to position, clamp and fix accurately
- Type 05 - The use of a ladder beam as wall plate proved to be entirely inefficient, and due to the nail laminated nature of the ladder, there was quite significant inaccuracies involved in this arrangement.

Figure 9.89: Installation and preparation of timber piles to receive primary structure



- a) With the positions of the primary structural nodes set out and marked the first stage of the installation is to create a pilot hole using a large diameter steel bar, to a depth of 500mm and diameter of 150mm. The gate post is then positioned in the pilot hole and manipulated to vertical. A 180kg weight is dropped onto the head of the post repeatedly until the hammer impact causes very little movement.
- b) Once installed the piles were cut down approximately using a chainsaw and finished levels marked out using a water level. Levels are set to give a finished floor level at a step above the hardstanding, this could potentially have been lower however the need to access and work with the heads of the timber piles to apply pile caps required this additional height.
- c) With the piles trimmed to height, the centre line of the primary structure is set out using a chalk line and the pile is notched to receive a timber packer applied to the internal face of the pile to increase the bearing area. With the timber packer corrected for levels, large diameter holes are then drilled through the pile and packer.
- d) Prior to the installation of the packers, all surfaces of the pile and packers, including bolt holes were generously coated with black timber preservative. The packers were then glued and bolted in place and a final coat of preservative applied.

9.07 CONSTRUCTION

9.07.1 CONSTRUCTION : SUBSTRUCTURE OF TIMBER PILES

The use of timber piles to provide a temporary, low impact substructure was proposed as a research exercise to test the durability of homegrown timber in load bearing and ground contact conditions. With limited guidance and reservations expressed by consultants, it was embarked upon with some uncertainty. Figure 9.89 illustrates the construction process.

In addition to furthering research interests into homegrown timber in construction applications, offered the opportunity to significantly reduce the impact of construction on site, potentially removing the need for significant earth movement and permanent concrete based footings. In reality however, the need to provide a decent working surface and achieve an appropriate finished floor level resulted in the immediate site being significantly re-landscaped. The use of point footings and a suspended timber floor removes the need for a flat load bearing substructure. However in typical timber panel construction a concrete ground bearing slab will be employed as a primary working platform, on which materials can be stored and assembled and safety platforms erected. In the absence of a ground bearing slab, the ground finish becomes the primary working platform raising considerable safety concerns, particularly the affect of inclement weather conditions on the steeply sloping topography.

The specification of point load footings in place of a ground bearing slab also placed increased demands on the setting out process and the accurate positioning of point load footings in relation to the primary structure. This proved to be a highly inefficient process when applied to the Tregynon site. The nature of the footings and their installation, and the lack of any definitive fixed setting out point in both horizontal and vertical directions, resulted in simple chalk lines and fixed posts requiring constant reconfiguration to allow access and adjustment to the changing working heights.

Despite the potential for a high level of inaccuracy, timber piles were somewhat fortunately accurate to their intended locations. However in order to allow a greater level of tolerance for the driven piles, packing timbers and bearing plates were installed to increase the bearing area. This process was performed in place and once again resulted in a significant level of inefficiency. This was largely due to the awkwardness of working around the timber piles in close proximity to the finished ground level.

The installation of piles proved to be a reasonably efficient process. With the support and machinery of a local farmer, it was achieved over two afternoons with each pile taking approximately half an hour to install. However the methodology does pose considerable concerns over the quality and accuracy of installed

Figure 9.90: Preparation of site and services



a) Site levelled using a mini digger and adjacent sycamore tree removed. A service trench is prepared from Bay 1 to the existing sanitary facilities in the Old Sawmill.



b) Cold water supply, armoured electrical cable and waste pipe laid into trench on sand base. Safety tape laid above electrical cable and trench infilled with layer of sand and pea shingle.



c) Site is levelled and cleared and a layer of sand laid across the site.



d) A heavy duty weed barrier membrane is cut and fitted around services and piles and weighted with pea shingle.

piles, and would need significant improvement for formal constructions.

9.07.2 CONSTRUCTION : SITE & SERVICES

The area of site chosen for the building is heavily sloping, in both North to South and East to West directions. As previously discussed, the original site topography raised considerable concerns over working conditions. It was therefore determined that the site would be landscaped to an intermediary level, allowing the primary structure to be positioned at a significantly lower height whilst maintaining a minimum ventilated zone below the suspended timber floor. The immediate site was therefore re-landscaped using a mini digger, with the majority of the top soil reused in the immediate vicinity. In order to ease problems with drainage in the area, a mature but poor quality Sycamore tree was also removed immediately adjacent to the proposed building.

Although it is proposed that a unit of this type could operate autonomously from the main service connections it was decided to make provision of an electrical and fresh water supply and a waste outlet. A trench, to a depth of approximately 500mm, was prepared from the edge of the existing building to positions immediately below the sanitary facilities in Bay 1 of the proposed studio. Pipes and armoured cable were laid out, covered with appropriate identification safety tape and recovered with hardcore, sand and topsoil. The inclusion of a substantial ventilated zone below the suspended timber floor is a great asset in the distribution of large services such as soil pipes which can remain outside the building fabric before entering immediately below the intended location. However this requires careful planning and setting out prior to the assembly of the frame.

With services installed the site was cleared and covered with a layer of sand. A heavy duty membrane was laid across the site, cut round piles and weighted down with a layer of pea shingle. In the case of a whole house construction it is likely that a more durable hard landscape will be required to ensure that drainage is maintained and additional requirements such as radon barrier and sump is incorporated where necessary.

Figure 9.91: Assembly of primary structure to Bay 1
day 1



- a) Assemble ground floor beams
- Fill with Insulation
 - Fix OSB + DPM to underside
 - Mark, drill, pilot and fix steel shoes to underside
 - Install connectors and shear connectors
 - Locate primary beams 3 + 4 on pad footings
 - Locate spanning edge beams on shear plates
 - Set out for squareness and levels using diagonals
 - Temporarily fix

- b) Prepare bonded-in threaded rod foundation connections
- Mark bolt positions of steel shoe connectors
 - Remove ring beam from location by jacking up onto timber packers and sliding to either side of the pile caps
 - Drill down into pile cap to a depth of 180mm
 - Turn glue into the thread of the cut to length rod and the cleared hole and insert into the pile cap
 - Remove excess glue

- c) Lower ground floor frame onto foundations
- Install steel bearing plates onto each pile cap
 - Return ring beam assembly to a position directly above threaded rods
 - Lift frame and remove packers to lower the frame gently onto the pile caps locating threaded rods into the foundation connector
 - Level with packing pieces, square and apply washers and nuts to each threaded rod

9.07.3 CONSTRUCTION : PRIMARY STRUCTURE : BAY 1

The assembly process of Bay 1 was designed to study the efficiency and accuracy of the frame if installed as individual components. A ground floor ring beam is installed first providing a working platform for columns, eaves beams and roof trusses to be installed in sequence. This process provided a number of observations.

The weight of the steel based connectors are a significant hindrance to the general assembly of the frame. The weight of connectors is purposely increased beyond that of the standard timber based connectors therefore future constructions will not be affected in this manner, however the construction process for Bay 1 has been significantly affected by the need to safely manage the weight of these components.

The intention to employ the ground floor ring beam as a template for setting out the foundation fixing points was found to be simply unmanageable due to the weight of the assembled structure. The removal of steel from the connectors would reduce the assembled weight by approximately 80kg which may make the intended construction process feasible, however the size and scale of the assembly would suggest that moving the structure once assembled by hand is not a realistic proposal.

As the setting out and positioning of the ground floor ring beam in order to mark up fixing points took approximately one hour, it would seem inefficient to then be required to dismantle the frame in order to complete the installation of foundation fixings. However once the frame is assembled it is not possible to gain access to the pile caps in order to drill pilots holes or glue in the threaded rods. In addition it is not possible to remove or install fixings between the ground floor beam and steel foundation connector, as the distance between flanges of the connector cannot accommodate the entire length of fixing and tools.

Issues with the dimensional accuracy of the prefabricated steel and timber connectors and the installation of anchor bolts severely delayed the assembly of Bay 1. With these issues resolved and all components prepared accurately for assembly it should be possible to assemble the entire frame in a matter of hours.

The installation of a ground floor and intermediary floor structure in parallel with the frame assembly provided an essential working platform for the continuation of the frame assembly in the absence of a scaffolding tower.

The safe installation of columns offered a number of challenges initially due to the length and weight of columns and the operating height of the ground floor connectors above a safe working platform. Once assembled the connector arms to receive columns were located at a height of approximately 1m above ground level and 400mm above the working platform of the ground floor frame.



day 2



day 3



d) Install Columns

- Install a temporary ground floor platform and scaffolding
- Fill columns with insulation and fix shear connectors for eaves beams and intermediary floor beams
- Drop columns over upstanding end of connectors
- Temporarily fix

e) Install spanning eaves and intermediary floor beams

- Fill spanning beams with insulation and pilot drill fixing holes
- Working from temporary platform and scaffolding drop spanning beams onto shear plate connectors
- Level and fix one column ensuring column is vertical
- Working from the fixed column, level, square and fix columns and beams using braces and
- confirm accuracy with diagonal measurements

f) Install roof trusses

- Install a temporary intermediary floor platform and temporarily fix safety barriers to the column uprights
- Fill roof trusses with insulation and pilot drill fixing holes
- Assemble roof trusses on temporary platform at eaves level to form a triangle with eaves and ridge connectors temporarily fixed
- Rotate truss to vertical with connectors gently lowered into open column ends
- Fix connectors

This posed a considerable handling challenge as columns had to be lifted and dropped vertically down on to the upright connector arms. Working from floor level platforms the rotation and lifting of columns vertically was particularly challenging due predominantly to a lack of any appropriate hand grips. Therefore there was considerable risk of overbalancing, or dropping of the vertical column. An alternative approach was taken for the final column. Four lengths of timbers were temporarily fixed horizontally to the faces of the remaining column at approximately 500mm from the bottom edge. Working from a scaffolding platform adjacent to the top edge of the connector the column is righted to vertical and lifted vertically using the makeshift handles to drop onto the connector. This enabled a much more controlled process and was considerably safer. The working height does pose a considerable concern when considering safe manual handling loads, and the box section form, specifically when vertical, is not inherently easy to handle.

9.07.4 CONSTRUCTION : PRIMARY STRUCTURE : BAY 2

The assembly of the primary structure for Bay 2 looked to test the process of assembling a 2 dimensional portal frame at ground level, before rotating up to its vertical location. This process has been the common method employed for timber cruck framed construction and offers a number of potential benefits;

- Assembling at ground when horizontal offers the potential to efficiently set out and square the frame more accurately than if vertical as all junctions can be easily accessed and manipulated at ground level, on a level working platform.
- Working at ground level can provide a safer working environment for multiple people, including the safe manipulation of large and heavy components, than may be permitted if working at height from scaffolding.

To date this method of assembly has been used for the majority of the smaller temporary structures constructed by the Project Team due to the weight and scale of components and the need to minimise any scaffolding requirements. The construction of the Welsh Pavilion involved the assembly of a complete portal frame at ground level, which was then lifted into location by forklift, see figure 9.84. However the process has not been employed on a structure of this scale by hand. Therefore the process proposed, as shown in figure 9.96, required the assembly of the portalised frame adjacent to its final location, with the frame lifted to vertical and dropped onto its foundations. Figure 9.95 shows the progress of this study. The study was severely hampered by the weather conditions on the day however a number of key observations could be drawn.

In order to recognise the benefits associated with assembling the frame at ground level, a good level surface was required to assemble the frame on. This was not possible on the immediate site due to the steep topography, and the weight



Figure 9.92: Lifting a traditional cruck frame by hand

Source : Amgueddfa Cymru — National Museum Wales



Figure 9.93: Lifting a traditional cruck frame with the assistance of a triangular truss

Source : Amgueddfa Cymru — National Museum Wales



Figure 9.94: Lifting the horizontally assembled portal frame using a forklift onsite for the Welsh Pavilion.

Figure 9.95: Assembly of primary structure to Bay 2
day 1



day 2



- a) Assemble portal frame on temporary platform adjacent to the foundation footings.
- Square and fix all connections.
 - With Portal and Steel foundation connections located directly over footing rotate portal frame up to vertical
- b) Once righted to vertical, hold in place and in a controlled manner lower portal frame onto timber pile foundation locating the steel foundation footing onto threaded rods. This operation is provided by lowering the assembly frame using a pallette jack.
- Fix temporary battens at eaves line.
 - Apply washers and nuts to bonded-in threaded rods.
- c) Square and level portal frame and lower ground floor edge beams and eaves beams onto shear plate connectors and fix in place.

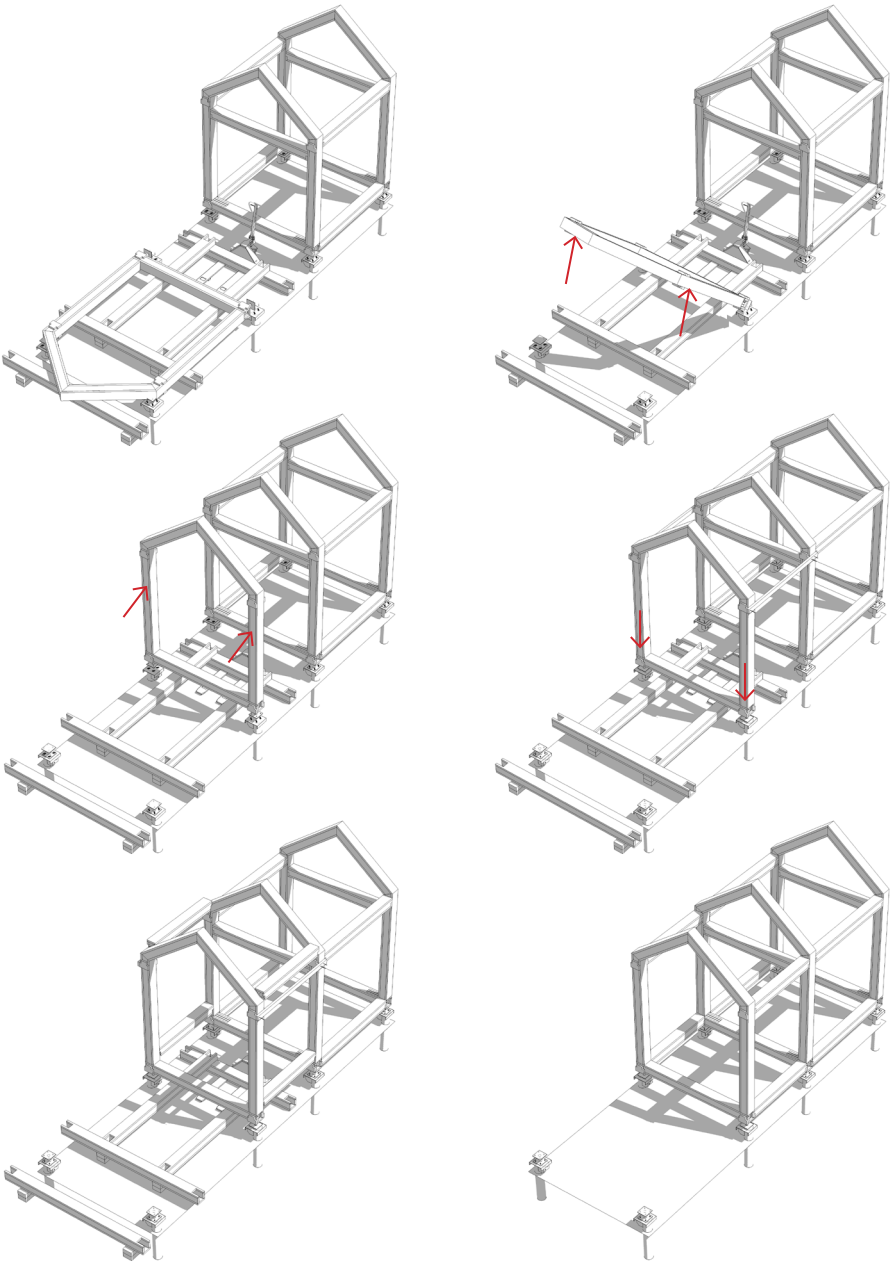


Figure 9.96: Proposed assembly process for Bay 2 primary structure drawing on the traditional cruck frame construction approach.

- a) Set out foundation fixings using template
- Make up template of primary structure using 210mm wide 18mm OSB
 - Set out template on pile caps using bay 1 as the setting out references
 - Pilot drill threaded rod locations as indicated by the OSB template
 - Prepare 180mm deep holes to receive threaded rods
 - Glue in threaded rods
 - Remove excess glue
- b) Set up temporary platform and assemble portal frame at ground level
- Using box sections, breeze blocks and a pallette jack set up a temporary platform at a position just above the foundation footings,
 - Assemble portal frame, including roof truss, then square, level and check dimensions and fix connectors,
 - The weight of the roof truss and length of the portal frame made it very difficult to construct a suitable platform on the sloping ground making it very difficult to install the roof truss and square up the frame accurately
- c) Rotate frame to vertical and lower onto foundation footings
- With the roof truss removed and the connectors temporarily fixed the frame is rotated to the vertical position
 - Once vertical the frame is adjusted to a position directly over the bonded in threaded rods and gently lowered onto the foundation footing using the pallette jack to control the speed of drop.

of components made the moving of a completed frame from a more suitable location unfeasible. Therefore a temporary framework was assembled using 3m box beam sections adjacent to the foundations on which the structure could be assembled. It was incredibly challenging and time consuming to assemble a framework that could provide a suitable, robust assembly platform on which the frame could be set out, squared, levelled and fixed. The process took a significant portion of the day, and could only be employed for the assembly of one portal frame.

A traditional cruck frame is typically assembled on the flattened and hardened mud or stone floor of the building, with the lifting party walking the frame up to vertical on its pad stone, with a heavy stop such as a large stone employed to stop the frame from slipping. The timber pile foundation type resulted however in

day 3



- a) Fix temporary restraints at eaves level and install spanning edge beams
- Once in place, apply nuts and washers loosely and fix temporary restraints at eaves level.
 - Check the level and location of the ground floor beam in relation to the existing structure and adjust with packing pieces between foundation footing and bearing plate where necessary. This is particularly heavy work with columns installed.
 - Drop in edge beams, check level and fix in place.

- b) Install Eaves beams
- Remove temporary restraints and drop eaves beams onto shear plate connectors using a spirit level and measuring diagonals confirm column and eaves beams are level and perpendicular and fix in place
 - Ratchet clamps were useful at this point to pull the column at A2 to vertical and hold whilst the eaves beam could be fixed, however the columns required considerable force to adjust.

- c) Install roof trusses
- Working from scaffolding, assemble a temporary platform of joists at eaves level and assemble roof trusses and connectors with temporary fixings
 - Rotate to vertical the roof trusses guiding the eaves connectors into the hollow of the box section columns.
 - It is key that the roof truss is guided into the columns symmetrically and dropped evenly otherwise the connectors can lodge.

an area of just 300x300mm at a height of 300mm above ground being available to land the frame onto. The frame with foundation connector installed, was therefore assembled and rotated at a height of approximately 500mm above ground and once vertical, then lowered onto its foundation fixings. The height of the frame off ground made lifting by hand incredibly challenging as the 3 - 4 men employed to lift could only reach to a point less than half the distance of the frame column.

The frame was subsequently lifted to vertical without the additional weight of the installed roof trusses. This still proved to be physically challenging due to the lifting height however once vertical, the frame was relatively easy to shift into position above the installed foundation fixings. A pallette jack under the frame was employed to lower the frame onto the fixings in a controlled movement. Roof trusses were subsequently installed independently working at height from a scaffolding tower.

Although the process could not be completed as proposed a number of conclusions could be drawn from the study;

- The frame, without roof trusses in place, was able to flex significantly, therefore the setting out and squaring performed at ground level was largely ineffective.
- The site and foundation type, specifically their height above ground, was more significant to the process than the weight of components, making the lifting of a completed portal by hand largely impossible.
- The use of machinery may have made this process easier however the scale of machinery required to lift the frame would have been challenging to accommodate on the heavily sloping site and proud foundations.
- The use of winches and mechanisms may have assisted the hand lifting of a completed frame however it is not clear how this could be achieved safely without a framework already in place to lift from.
- Further labour would have likely been a hinderance rather than assistance due to the limited working area available at ground level.
- Scaffolding at height enabling further lifting capacity closer to the ridge could possibly be incorporated but it is challenging to determine a safe arrangement in a restricted working area.

Figure 9.97: Assembly of primary structure to Bay 3
day 1 day 2



- a) Set out foundation fixings using template
- With anchor bolts installed already, the ground floor beam with foundation connector in place is dropped into place and nuts and washers loosely applied.
 - Edge beams are dropped into location. Levels and diagonals are checked and adjusted where necessary using packing pieces and ratchet straps.
 - Edge beams are fixed in place.



- b) Install columns
- Working from a scaffolding tower set 1m above the ground floor beams columns are first lifted onto the scaffolding tower and then rotated to vertical whilst being lowered, guided from below, down onto the upper arm of the connectors.



- c) Eaves beams and gable spanning beam installed
- Working from the scaffolding tower, eaves beams are dropped down onto shear plate connectors.
 - Working from the installed frame of bay 2 the structural openings are checked for squareness and levels and columns, eaves beams and gable beam are fixed to connectors to hold the frame square.



- d) Install roof truss
- Install a temporary ground floor platform and scaffolding
 - Fill columns with insulation and fix shear connectors for eaves beams and intermediary floor beams
 - Drop columns over upstanding end of connectors
 - Temporarily fix

9.07.5 CONSTRUCTION : PRIMARY STRUCTURE : BAY 3

It was initially intended that Bay 3 would employ and test construction with a multi directional connector. However due to the limited time and funds available, this proposal could not be fulfilled. In addition it was proposed that the primary and secondary structures of Bay 3 could be completed in parallel, employing infill panels as a method of accurately setting out the frame. Following the challenges that were met with the construction of Bays 1 and 2, it was decided that these processes would prove to be incredibly challenging and over complicated. Once assembled, with solid connectors in place, the primary structure is extremely difficult to manipulate. The limited tolerances between connector and frame result in it being very challenging to correct any discrepancies in the geometry of the primary structure. The installation of panels in parallel, as witnessed in the construction of the ERC, would inevitably restrict this process further, including limiting access to the fixing points for frame connectors. The primary structure for Bay 3 therefore repeated the assembly process of Bay 1, with components installed as individual elements, working from a series of safe working heights.

A number of further observations were provided by this process;

- The inclusion of a spanning beam at eaves level in the gable end enabled the frame of columns and eaves beams to be squared and levelled prior to the installation of the roof trusses. The gable end beam acted as a positive restraint to the columns easing the installation of temporary fixed roof trusses.
- The shear plate arrangement, which provides a safe support for the edge beams without the need for fixings, enables a good amount of manipulation of the ground floor ring beam, to square and level the frame prior to the installation of fixings.
- The quantity and density of insulation installed into box sections needs to be carefully controlled as the solid section connectors are not able to displace the insulation if overfilled. This results in joints becoming extremely challenging to accurately close.

Figure 9.98: Installation of infill panels to Bay 1
day 1



- a) INFIL 1: Bay 1 Floor
- Install ground floor panels by dropping evenly between primary structure and sliding into position,
 - Each panel is installed in turn and slid into position
 - Once all panels are in place, fixings are installed through the flange of each joist hanger into the primary structure
 - A floor deck of 600mm wide OSB is installed perpendicular to ladder beams and fixed in location to complete the buildup.

day 2



- b) INFIL 1: Bay 1 Intermediary Floor
- The intermediary floor is installed in the same manner as the ground floor structure
 - Floor panels are installed and fixed prior to the installation of wall panels to provide access to the primary structure on which joist hangers are supported
 - Panels are lifted from below working from the ground floor platform with panels passed through the opening at an angle and lowered into location
 - With panels hanging in place on joist hangers, a temporary deck of OSB can be applied and used for access to fixing points to complete the installation.



- c) INFIL 4: Bay 1 South Wall
- Open wall panels are installed with a 9mm OSB sheathing applied. OSB sheets are patched along the panel length to provide overhangs to the top and bottom of the panel
 - Panels are inserted and fixed with nails driven through face fixed joist hangers and screws inserted through the exterior sheathing
 - A second layer of 9mm OSB is applied on site overlapping the primary frame and staggering with panel joints to ensure that loads can be adequately transferred across joints.



Figure 9.99: Manufactured ladders with top hung joist hangers fixed into bottom boom, with 9mm OSB packing piece to increase depth.



Figure 9.100: Access to face fixed joist hanger fixing points is extremely limited when adjacent to primary structure.

9.07.6 CONSTRUCTION : SECONDARY STRUCTURE : BAY 1

During the construction of the primary structure for Bay 1, the proposed floor and intermediary floor panels were prefabricated and loosely installed to provide a temporary working platform and a protective roof. This demonstrates an immediate advantage of joist hanger based panels, as the flange joist hangers provide a stable structure when installed between the primary structural elements. With the primary structure complete and the majority of panels prefabricated, the temporary installation was confirmed with fixings and a suitable working environment was created to install prefabricated wall panels.

REFLECTION

- Designed specifically for I joists, the identified joist hangers required fixings to be installed into the bottom boom of the joist. However due to the density of crimped nails in the end section of each boom, joist hanger fixings often met ladder nails, causing the hanger to twist or shift out of place.
- With a single fixing into either side of the bottom boom, the joist hanger is very susceptible to damage prior to installation. When installing panels this often resulted in face fixed hangers bending and snagging against the rough surface of the OSB.
- The centring of ladder beams to ensure face fixed joist hangers do not collide resulted in a lack of sufficient access between ladder beams to install fixings into the primary structure and to provide a suitable connection between panels, see figure 9.100.
- For top flange hangers to be fixed, floor panels need to be fully installed first, prior to wall panels, in order to have access to the primary structural beam. This is not considered a problem at ground floor where installing panels first provides a useful working platform, however at first floor the installation of floor panels prior to wall panels poses a conflict if the internal skin of wall panels is to be used as a diaphragm skin.
- With the installation of roof panels, the top flange joist hangers significantly reduce the amount of working at height required as all but the top panels can be installed and fixed from inside the building. However ridge panels do require nailing from outside, and additional OSB infill pieces are required externally to complete the roof deck.

Other observations from the installation of secondary structural panels in Bay 1 include;

- The reduced 2.1m height of the East Wall allowed full height panels of 18mm to be employed to provide overlapping diaphragm infill panels which are extremely robust with fixings made directly between sheathing



d) INFIL 10: Bay 1 East Wall

- Open prefabricated infill panels are installed into the structural opening from the exterior of the frame
- Overlapping external sheathing acts as a stop to all structural edges
- Nails are installed internally through the fixing points of the face fixed joist hangers and screws are installed externally through OSB sheathing to provide a racking panel specification
- Loose ladder beams are installed into the structural opening of the full height window to form jamb lining.

day 3



e) INFIL 14: Bay 1 North Wall

- Panel is assembled in place but considered as a full wall section panel, with primary structural components integrated into prefabrication
- Loose ladders are installed as studs at equal centres
- Predrilled packing timbers are fixed into the end web of each ladder directing skewed screws at a 40° angle into the primary structure
- A sheathing of 9mm OSB is staggered across the wall panel width
- A second sheathing of 9mm OSB, proposed as the onsite work in a prefabricated scenario, is applied to overlap the primary structure.

day 4



f) INFIL 7+17: Bay 1 Roof

- Prefabricated open roof panels are installed from within the structure, working from the intermediary floor platform.
- Bespoke eaves panels are cut to angle and installed first, fixed through an external sheathing into the primary structure.
- Standard infill panels are lifted through the frame opening at an angle and brought to rest on the shoulders of joist hangers and the installed eaves panel.
- One pitch is completed from the interior including fixings and all but the final panel of the second pitch is also installed from the interior. The remaining panel and fixings, including ridge panel are installed from the exterior of the structure.

board and primary structure. The overlaps provided an accurate setting out guide in relation to the primary structure, making it very straightforward to locate and fix the panels in location.

- The 9mm OSB external sheathings employed for Infill Panel 4 were not sufficiently rigid to form the basis of prefabricated panel, being very susceptible to damage and allowing a considerable amount of flex. This is particularly due to the omission of any wall plates providing additional rigidity across the width of the panel. The application of 9mm OSB on site was straightforward and suitably completed the required diaphragm fixings however the quantity of onsite work was too high to make the prefabricated system justifiable.
- Infill Panel 14 was considered as a full panel construction, with ladders, sheathing boards and box sections combined off site before being dropped in to place as a full panel. It was not possible to complete the assembly off site as proposed due to the need for significant lifting equipment, however the detailing was replicated in place. Ladder beams are directly fixed into the primary structure edge beams using predrilled and cut packing timbers applied to each side of the end webs to direct skewed screws through the ladder beam web into the beam. Screws are designed to be skewed through both the end web and the opposite packing piece to meet the box section at an angle of approximately 40°, however some trial and error was required to achieve this and successfully miss opposite directed skewed screws. This simple fixing detail proved to be largely successful however significant fixings with a length of 100mm were required to bed adequately into the primary structure. A plywood spacer positioned between the primary structure and ladder beams was employed to set out and stop the ladder from slipping as screws are fixed.
- The sheathing of Infill Panel 14 required adjacent 9mm OSB sheets to be landed suitably on a single 60mm ladder boom in order to provide direct connection between panels in the staggered sheathing layout. It proved challenging to design an efficient layout of staggered and overlapping boards to land accurately on ladders. The 30mm width of ladder boom available for fixings also proved to be too restrictive with fixings missing or not providing a robust connection and 9mm OSB breaking up due to the proximity of the fixing to its edge. The arrangement of multiple layers of OSB would appear to offer a potential solution to full wall panel off site fabrication, with panels being transportable to site with a primary sheathing of 9mm OSB added to onsite when combined with infilled portal frame panels, with a secondary layer of 9mm OSB to complete a diaphragm structural panel.

Figure 9.101: Installation of infill panels to Bay 2
day 1



a) INFIL 2: Bay 2 Floor

- Install loose plywood tongues into each panel to create a male/female connection.
- Drop panel into place to rest on prefixed bearing plates and slide into location with tongues located in the neighbouring recipient groove
- Fix through panel plates directly into bearing plates
- Once panels are in place, install the spanning edge beam, located on t-plate shear connectors to complete the floor construction.

day 2



b) INFIL 5: Bay 2 South Wall

- Install sole and head plates, fixed into the primary structural elements (this could be included into the prefabrication of the primary structural elements with a potentially greater level of accuracy)
- Panel is then slid in to location from the exterior of the structure and fixings installed through panel plates directly into the sole and head plates



c) INFIL 15: Bay 2 North Wall

- Processes are repeated from Infill 5 to install two panels to the north elevation with the only difference being the addition of fixings installed through the vertical external overlap provided to the edge of each structure panel. Fixings pass directly through OSB into the primary structure to provide a vertical diaphragm connection.

day 3



d) INFIL 8+18: Bay 2 Roof

- Eaves panels are installed and fixed through external OSB overlaps directly into the spanning eaves beam.
- All roof panels are lifted from within the studio working from a small scaffolding tower, rested on bearing plates and slid into location with tongues making connection with neighbouring panels
- The final ridge panel is then installed from above and fixings installed through panel plates into the prefixed bearing palte.

9.07.7 CONSTRUCTION : SECONDARY STRUCTURE : BAY 2

Bay 2 proved to be considerably simpler to construct than Bay 1. Figures.. illustrate the construction processes involved.

The provision of a bearing plate or sole and head plates prefixed into the primary structure, provide a robust bearing for closed infill panels to be dropped into place and rested while any adjustment and fixings are installed. This eased the assembly considerably allowing for panels to be temporarily inserted and safely used as a load bearing platform prior to being fully installed. This is a key benefit of the system as other tested panel arrangements required support whilst fixings are installed, requiring more than two labourers and resulting in less control of accuracy.

The provision of loose plywood tongues enabled closed panels to be individualised when ready to install. Panels could therefore be installed in any order and in any position simply by removing or installing the loose tongues. The sliding together of panels was designed to be purposefully tight however the installation highlighted a number of considerations with tolerances;

- The close tolerances of panels within the primary structure allowed for very little misalignment or discrepancies in size. When attempting to slide or drop panels into location, panels therefore had to be evenly balanced and moved as they could easily become wedged if force is applied when out of alignment.
- The purposefully tight tongues positioned in both the top and bottom flanges of the panel provided a very tight joint when offered up to its recipient groove and in cases significant force was required in the form of straps or a hammer to close the gap. Although concerning in terms of ease of buildability the tightness of this connection was very reassuring, providing reasonable confidence that the joint would ensure panels would act to distribute loads evenly across neighbouring panels.
- The installation of the final panel proved to be particularly difficult as it was designed to align with the tongue and groove connection at 45° and then rotate to meet the bearing plate, thus failing to connect with the primary columns, see figure 9.101a. In reality this was very tight and the grooves required some adjustment to allow additional tolerance in the joint.

Once completed the system offered the conclusion that a greater level of dimensional tolerance could be permitted without necessarily reducing build quality. The geometry of joints and the lapping of materials would ensure that all structural connections could still be made sufficiently if panels were reduced by 2-4mm, and the reduced air tightness would not cause any additional concern. The study also suggested that the assembly process could be made more

efficient by performing the installation of panels, specifically floor panels, in combination with the assembly of the primary structure.

The manual handling of closed panels up to 2.4m could be easily and safely managed by two people, with floor, wall and roof panels all installed by hand using a small scaffolding tower. Once located within the structural opening, panels were well supported and could be safely completed by a single person. The safe manoeuvring of panels was only hindered by the lack of positive hand holds, particularly to the interior of the panel, however temporary handles, or the integration of prepared insulation holes or service void battens into the prefabricated panel could provide a suitable integral grip.

As roof panels were primarily installed from the interior of the building working from a small scaffolding tower, work at height is limited and generally retained within a controlled working environment. The majority of fixings however are installed to the exterior of the building. The provision of a small scaffolding tower wasn't sufficient for this purpose leaving the safety of processes susceptible to weather conditions, clearly demonstrated in the studio construction. Although not uncommon to traditional construction this resulted in processes, particularly at roof level, that had high levels of risk associated. Common working practices such as the provision of fixed temporary rails and guards fixed into the roof panels therefore provided access to all fixings points to the roof, thanks largely to the immediate robust nature of the installed but unfixed infill panel and bearing plate design.

Perhaps most satisfying about the construction of Bay 2 was the ease at which a number of non skilled individuals could take up delegated tasks. Instructions could be easily disseminated to a range of skill levels and in general the simplicity of the detailing made this process easy for individuals to envisage and understand and safe to complete.

Figure 9.102: Installation of infill panels to Bay 3
day 1



a) INFILL 3: Bay 3 Floor

- Prefabricated open floor panels are dropped into the structural opening and propped in position whilst fixings are driven through panel plates
- An OSB sheet to the underside of the frame acts as a support and guide whilst fixings are installed.
- Panels can be installed in any order from above or below
- With the panels in place prefabricated panels of Sitka spruce are installed as an internal sheathing.

day 2



b) INFILL 16: Bay 3 North Wall

- Prefabricated open wall panels are installed from the exterior and sheathing boards aligned with external face of primary structure.
- Fixings are installed through alternative arrangements of panel plates, directly into primary structural beams at ground and eaves.
- Precut OSB sheathing boards are applied to internal face of ladders to overlap neighbouring panel by half a ladder beam

c) INFIL 6: Bay 3 South Wall

- Prefabricated open wall panels are installed from the exterior and sheathing boards aligned with external face of primary structure.
- Precut 600mm panels are employed to provide support to above window panels while fixings are completed.
- A precut solid section panel plate is fixed into the notched end of below window ladders to form a sill and above window ladders to form a head.

9.07.8 CONSTRUCTION : SECONDARY STRUCTURE : BAY 3

In comparison to Bay 1 and 2, the construction of Bay 3 demonstrated a number of useful learning points, but perhaps most significantly highlighted the additional efficiency offered by the closed panel system employed in Bay 2. Figure 9.102 illustrates the construction processes.

Open panels were designed to test and compare a number of alternative panel plate geometries and in the most part little difference was recognised in the efficiency and accuracy offered during construction. In all cases panels were easily fixed into location with no issues concerning splitting or defects in the plates.

Unlike the closed panel system detailing, whereby a fixed timber plate provides a locator to each end of the panel, the design of the open panel system does not incorporate any type of integral positioning element to align the installed panel with the primary structure. In the case of floor panels, an OSB plate installed to the underside of the primary structure, see fig 9.102a, acts as a temporary bearer during installation, however this was found to be insufficient therefore panels required additional support and measuring to ensure accuracy whilst fixings are installed. Wall panels were similarly challenging to locate as panel detailing did not incorporate any form of integral stop, such as overlapping sheathing boards or fixed plates. Panels therefore had to be aligned by eye, with the assistance of a temporarily fixed timber batten. Once in place, panels proved to be stable and accurate, however an integral method of setting out needs to be incorporated to improve the efficiency and accuracy of the installation process.

Wall infill panels to opening 16 are designed to overlap with neighbouring infill panels and primary structures in order to enable direct connections between external sheathings. In general the overlap was found to be sufficient to make a robust connection into neighbouring ladders however as previously discussed conflict did arise with overlaps when arriving at an opening. In this case the south window structural opening is over lapped by a 30mm protrusion of 18mm OSB. As could be expected, cutting the panel to meet the structural opening on site proved to be a highly inefficient process resulting in compromises to both quality and health and safety.

With all panels installed to the floor, north and south walls and roof as externally sheathed open panels the process of completing the internal lining was embarked upon. As panels are dimensionally coordinated this process was much simpler and efficient than otherwise could have been, however, as previously mentioned, the respective efficiency of the closed panel system was clearly illustrated. Of particular note is the installation of internal sheathing to the pitched roof, which proved to be a physically challenging process. Working from below on a scaffold

day 3



d) INFILL 12: Bay 3 West Wall

- Prefabricated closed wall panels are installed from the exterior to abut sole and header plates fixed directly to the primary structure.
- Fixings are installed through sheathing and panel plate into the sole and header plates.
- Plywood tongues are inserted between panels to the internal and external sheathings but omitted adjacent to the opening.
- Solid section plates are installed at the sill and head of the window opening to provide a robust frame.

e) INFILL 13: Bay 3 West Gable

- Prefabricated closed wall panels are made up to the angles of the pitched roof and installed from the exterior to abut sole and header plates fixed directly to the primary structure.

f) INFILL 9+19: Bay 3 Roof

- Open panels with internal sheathings omitted are inserted between primary rafters from within the structure.
- Panels are held in place, supported on the OSB external sheathing and fixings installed through alternative panel plate geometries.
- With panels in place, precut OSB is offered up from the interior and fixed in location.
- Ridge panel is installed from the interior and fixings installed through external sheathings of roof panels from the exterior to complete.

tower, precut boards have to be offered up and fully supported whilst fixings are installed. The open panel system offered a number of positive outcomes, perhaps most important being the ability to be fully installed from within the structure, working from a stable and safe work platform, without the need to work at height to the exterior of the roof.

In light of the relative inefficiency of the open panel methods, it was decided to complete the construction of the west wall using a similarly detailed closed panel system in order to apply the method to a punched opening arrangement. This confirmed previously positive findings, and resulted in the completion of the structural opening including the formed opening, within one hour by non-construction based individuals. This included the application of bespoke closed panels to the gable end opening.

The accuracy of prefabricated panels was found to be generally high during the assembly of each bay however during the installation of closed panels to Bay 2, the primary structural columns were found to be out of line by up to 10mm. This caused considerable concern when discovered, and a number of methods including the application of straps and clamps were attempted to improve the alignment, however little adjustment was possible at this stage due to the robustness of the assembled structure.

With panels fully installed however the results of this discrepancy are minimal and unlikely to result in any significant knock on effects. It can be concluded from this process that although accuracy and tolerance is critical to the buildability of the system, the permittance of greater tolerances to ease buildability does not directly result in a recognisable loss of quality.

Figure 9.103: Completion of weathertight envelope



a) Prepare external skin for breather membrane

- Ensure that all panel fixings are completed around the building
- Infil all spacings between infill panels with 18mm OSB to complete a flat external surface
- Fold and staple damp proof membrane as a skirt around the base of the structure

b) Apply roofing felt

- Fix and infill all spacings between panels using 18mm OSB
- Apply roofing felt to the roof deck starting at eaves and allowing a minimum 150mm overlap between sheets. This was started prior to the installation of the roof panels
- The membrane is applied off a roll in one single length to cover openings and continue around corners without jointing.
- The main door is then cut at diagonals and the membrane folded and stapled into the opening.

c) Apply breather membrane

- Starting in one corner of the structure apply breather membrane to the external skin, smoothing and stapling at frequent intervals to make sure the membrane is tight and smooth.
- The membrane is applied off a roll in one single length to cover openings and continue around corners without jointing.
- The main door is then cut at diagonals and the membrane folded and stapled into the opening.



d) Apply 25x50mm pressure treated softwood vertical battens

- Fix vertical battens at a maximum spacing of 600mm around the external walls and the roof pitches with fixings at a maximum of 600mm centres.
- A second layer of horizontal battens will be set out at centres determined by the layout of shingles.

9.07.9 CONSTRUCTION : WEATHER TIGHTNESS + FINISHING

The completion of the structural envelope largely completed the research objectives for the construction process of the studio, and coincided with a necessary review of the funds available for a future direction. It was therefore decided that as a short term solution to provide protection to the structure, the entire studio would be wrapped in a breather membrane and the first level of battens applied to ensure that the studio would be wind and water tight.

The installation of battens and membrane reinforced the need for an improved site arrangement providing a safe working platform to the full perimeter of the building to ease the use of a tower scaffold. The steep contours of the surrounding ground made this installation process considerably slower and less efficient, and increased the risk associated with working at height.

Figure 9.104: Assembly of Cedar Shingle material panel.



a) 25x50mm pressure treated softwood horizontal battens are set out at even centres.



b) A timber batten is employed to maintain a straight edge to the exposed end of the shingle.



c) Shingles are cut to length and predrilled to receive non corrosive fingers.



d) Shingles require a level of selection to maintain a reasonable consistent thickness to the exposed edge.

9.08 PROJECT EVALUATION

9.08.1 PROGRAMME & LABOUR ASSESSMENT

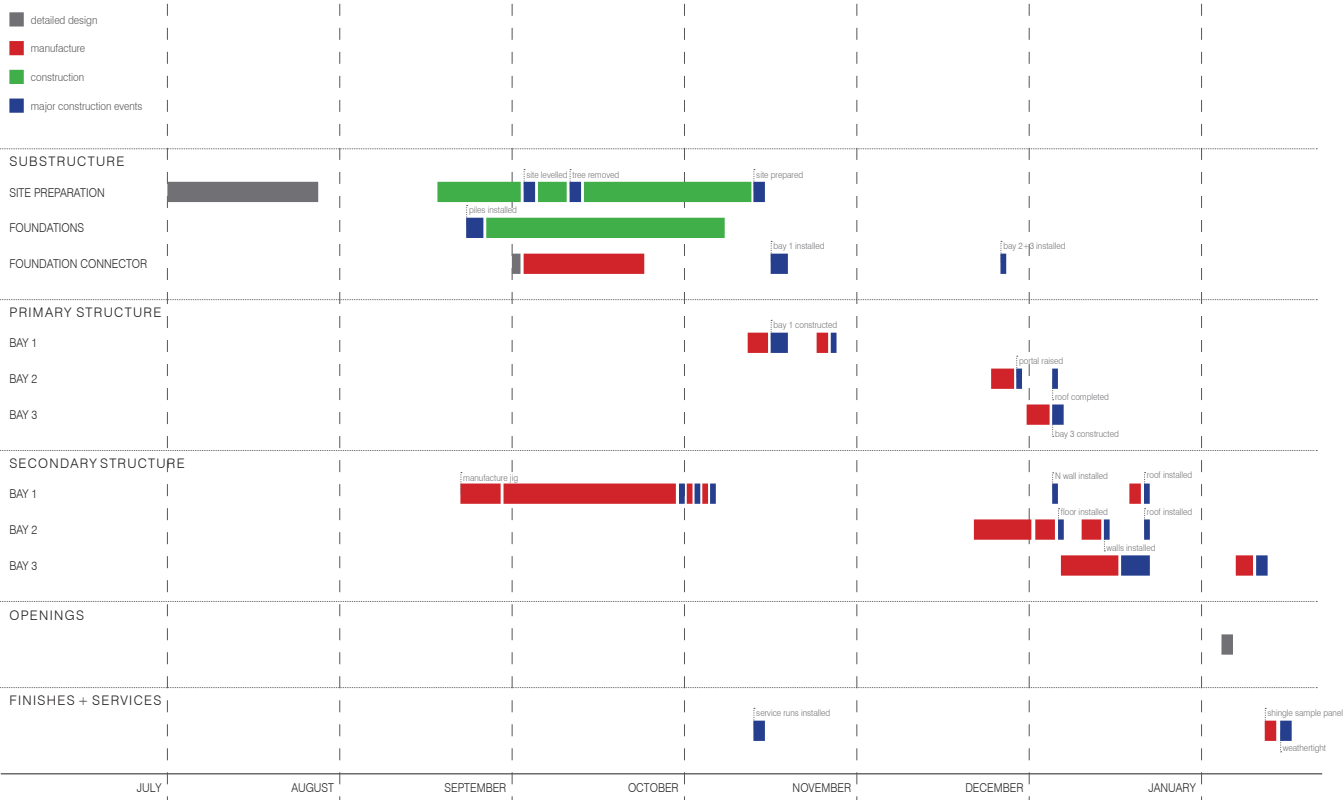
The assessment of the labour and construction programme for the Rural Studio must be considered within the following atypical context;

- Labour was extremely piecemeal with significant periods of manufacturing completed alone.
- Main construction phases were typically programmed to coordinate with the availability of helpers therefore manufacturing of components often coincided in parallel with constructions.
- Considerable time was required throughout the programme to prepare and protect the construction from often terrible weather conditions.
- A large number of people were involved throughout the project with varied skill and experience levels. Safety was therefore a priority with helpers often limited by what tasks they could perform. Considerable time was therefore invested in the dissemination of instructions and safety procedures.
- As a research study, considerable time and effort was committed to recording the manufacturing and construction processes as accurately as possible, frequently causing interruptions to progress.
- Many work processes, particularly during manufacture, were experimental and required considerable time investment with often limited success.

REFLECTION

- In total 75 days were spent on the manufacture and construction of the Rural Studio. This included the detailed design of components, jigs and working methods, and the preparation of all construction components. The majority of this time was spent working individually, with periods of contribution from members of the Coed Cymru staff. During this time 4 periods of concerted effort, typically in two or three day periods, were applied to the project with 3-5 people involved in the assembly of components and onsite construction. The project programme can be seen in Chart 9.2.
- Generally a single person could complete the majority of manufacturing tasks however the handling of infill panels required assistance once sheathings were installed due to the weight and scale of components.
- The majority of construction tasks required multiple personnel to assemble, adjust and fix components due to the weights involved. Two people could generally complete the majority of tasks efficiently without mechanical assistance. The primary structure required the greatest input of personnel due to the weight and scale of components and the height of the work

Chart 9.2: Construction programme of the Tregynon Rural Studio



areas above ground. The primary structure provided a robust support for the installation of infill panels thereby reducing the number of personnel required to install and hold in place panels whilst being fixed.

- Preparation of the site and timber pile foundations formed a significant part of the construction programme. Although installation of piles was relatively quick and easy, the preparation of the piles to receive the primary structure was extremely inefficient and is unlikely to offer an appropriate solution for general application.
- The study would suggest that the primary structure could be effectively set out, assembled, adjusted and fixed in a period of 2 to 4 days on prepared footings if all components are fully prefabricated.
- The installation of the west gable wall provided the most accurate demonstration of the potential build time. As a closed panel system, with wall plates prefixed to the primary structure, the wall, including a window opening, was completed including fixings in less than two hours. Extrapolating this across the remaining structure, infill panels could be installed in approximately one week.
- The installation of fixings required a significant input of labour due to the quantity and the length and diameter of fixings, which placed great stresses on the available tools.

9.08.2 COST ASSESSMENT

The Tregynon Rural Studio has provided a comprehensive set of data on which to assess the cost of the proposed construction system. A full cost assessment study has been performed as a set of independent cost calculations, first with the calculation of individual engineered components such as ladder beams and box beams, which are then combined to calculate simple structures. These calculations are then applied to the construction of a simple 2.4 x 2.4m single storey pitched roof structure, similar to that shown in Figure 9.105, to calculate a cost per square metre associated with the manufacture and construction of the primary structure and insulated thermal envelope.

ASSUMPTIONS

In order to complete the study it has been necessary to make a number of assumptions and estimations;

- The majority of labour requirements are assumed to be relatively low skilled tasks. Under guidance from Iwan Parry of the Pembrokeshire Timber Store these tasks should be met with a rate of £7.50 per hour.
- This cost assessment assumes and allows for a limited amount of overheads. A rate of £6 per hour is advised by Iwan Parry to cover energy

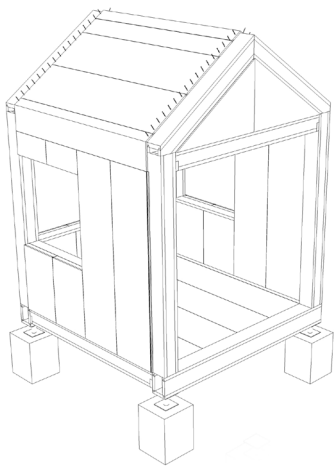


Figure 9.105: 2.4 x 2.4 pitched roof single storey arrangement

and accommodation costs and general wear and tear however it does not make allowance for capital investment, startup costs, finance and insurance, training or research and development.

- A rate of £15.00 per hour has been applied to labour costs where specialist sub contractors are required, in this case for the installation of Warmcel insulation into components. However it is likely that many of these processes could be taken in house at lower cost with sufficient training and equipment.
- The assessment assumes minimal material waste in line with the efficiency realised during the construction of the Rural Studio.
- Labour estimates are based on the experience of the Rural Studio however it assumes that material requires minimal pre processing prior to manufacturing ie sawn timber is supplied to the correct sections sizes. Additional processing tasks such as the ripping of 125mm boards to two 60mm planks are therefore removed from the calculation.

FINDINGS

Table 9.7 demonstrates the cost calculation for a typical 600 x 2400mm insulated closed infill panel suitable for walls, floors and roofs.

Table 9.8 shows the resultant estimations for each component type.

The calculations are based on material costs incurred during the construction of the Rural Studio. Generally these costs were generated from the purchase of small quantities of materials such as OSB and fixings through a trade account. Labour approximations are also based on the experiences of the Rural Studio and are generally based on relatively small quantities of repeated components. Although some efficiency savings were realised during the manufacture of components, specifically ladder beam manufacture, the limited number of identical components often resulted in time associated with familiarisation and adaptation.

In order to assess the effect of efficiency savings and economies of scale the study includes a comparative calculation for each component incorporating an assumed reduction in material and labour costs. Based on the manufacture of 100 units of each component, a saving of 20% has been applied to material costs and a saving of 40% applied to labour costs.

REFLECTION

- In general the individual component costs would appear very high. For example a 2.4m length of engineered ladder beam is calculated at £11.53, approximately 157% higher than the cost of the equivalent dimension of

Table 9.5: Cost Assessment of prefabricated 2.4m insulated box beam

2.4 m Box Beam					Notes
Item	Description	No	Price per Unit	Total Cost	
Material					
Flange Section	210x40mm C16 Sitka Spruce	2.00	4.64	9.27	£230 per m3
Web Section	170x40mm C16 Sitka Spruce	2.00	3.75	7.51	£230 per m3
Adhesive	Polyurethane Glue	1.50	2.00	3.00	Price per 100ml - £2.00
Insulation	Blown Warmcel to fill hollow section	0.04	43.90	1.76	130 x 130 x 2400mm = 0.04m3. Price per Bag - £10.87. Price per m3 - £43.9
Labour					
Prepare Timber	Plane to square edge, profile tongue and grooves and cut to length	0.25	13.50	3.38	
Assemble Box Beam	Assemble with glue applied, square and press	0.50	13.50	6.75	
Finish	Treat, cut joint geometry where appropriate and infill with Warmcel	0.50	6.00	3.00	
Insulate	Blow Warmcel Insulation into Closed Box Section	0.15	21.00	3.15	
Total				37.81	

Table 9.6: Cost Assessment of prefabricated 2.4m ladder beam

2.4 m Ladder Beam					Notes
Item	Description	No	Price per Unit	Total Cost	
Material					
Ladder timber	60x20 and 100x20 Sitka Spruce Falling Boards	0.02	230.00	4.46	£230 per m3. Quantity per Ladder = 0.019395 m3 £4.91 per 1000
Nails	2.8 x 75mm Galvanised Ringshank Nails	120.00	0.00	0.59	
Labour					
Prepare Timber	Trim Flange timber, Web timbers and infill timbers including selection	0.32	13.50	4.32	
Assemble Ladder	Assemble in jig and nail with handheld nailgun	0.16	13.50	2.16	
Total				11.53	

Table 9.7: Cost Assessment of prefabricated 2.4m closed and insulated infill panel

2.4 m Infil Panel					Notes
Item	Description	No	Price per Unit	Total Cost	
Material					
Preassembled Ladder Beams	60 x 190mm Sitka Spruce Ladder beams	2.00	11.53	23.06	Price per Sheet - £18.67 600 x 60 x 60mm = 0.00216m3 Price per 200 - £7.11 190 x 600 x 2400mm = 0.21888m3. Price per Bag - £10.87. Price per m3 - £43.9
Sheathing	600mm wide 18mm OSB/3 internal and external sheathing boards	2.00	9.34	18.67	
Panel Plate	60 x 60mm Sitka Spruce solid section	2.00	0.50	0.99	
Fixings	5 x 50mm Screws at 100mm Centres	112.00	0.04	3.98	
Insulation	Blown Warmcel to fill hollow section	0.22	43.90	9.61	
Labour					
Prepare OSB	Cut OSB to length and width, profile groove to each edge	0.50	13.50	6.75	Min 2 People
Prepare Timber Plates	Cut to length and section	0.10	13.50	1.35	
Assemble Panel	Assemble in jig and screw together	0.50	13.50	6.75	
Insulate	Blow Warmcel Insulation into Closed Box Section	0.33	21.00	6.93	
Total				78.09	

Table 9.8: Cost assessment of a prefabricated insulated structural envelope for a pitched 2.4 x 2.4m unit

Rates				
Labour Costs - Basic Wage	7.50			
Overheads	6.00			
Labour Costs - Specialist	15.00			
Efficiency Adjustment				
For 100 Units				
Material Costs reduced by 20%	0.80			
Labour Costs reduced by 40%	0.60			
Economic Assessment				
Description	Standard Engineered Components without Insulation	Insulated Engineered Components	Price Adjusted for Efficiency Savings	Notes
2.4 m Ladder Beam	11.53	11.53	7.93	60 x 190mm Engineered Ladder Beams and Studs
1.2 m Infill Panel	50.59	60.64	44.49	600mm Wide Closed Infill Panel of Two Ladder Beams with OSB Internal and External Sheathing
2.4 m Infill Panel	61.56	78.09	58.12	600mm Wide Closed Infill Panel of Two Ladder Beams with OSB Internal and External Sheathing
2.4 m Box Beam	37.81	37.81	26.99	210 x 210mm Hollow Box Section Beams and Columns with Warmcel Insulation Infill
Plywood Connector	29.25	29.25	20.16	Laminated Plywood and Softwood Connector
Shear Connector	6.44	6.44	4.07	Softwood T Shaped Spanning Edge Beam Connector
2.4 m Portal Frame	495.40	495.40	341.85	Box Section Beams Combined with Plywood Connectors to Form Structural Portal Frame
2.4 x 2.4m Post and Beam Frame	1211.18	1211.18	835.13	Portal Frames Connected with Spanning Edge Beams to Form Post and Beam Frame
2.4 x 2.4m Portal Frame with Infill Panels	3517.24	3975.16	2853.92	Post and Beam Frame Infilled with Closed Infill Panels with Formed Openings
Structure and Thermal Envelope - Price per m2	610.63	690.13	495.47	

solid section C16.⁷

- In general the majority of each component cost is associated with labour and overhead costs. The materials required for the manufacture of a ladder beam for example equate to approximately 44% of the total manufacturing cost.
- These calculated costs are generally in line with indicative approximations given by Kenton Jones Joinery suggesting that the assumptions made are reasonably accurate.
- Once combined as a full insulated structure including floors, walls and roof a total cost of £690.13 per m² is estimated. This price per m² is very high when compared with alternative timber frame kit manufacturers such as those supplied by Potton at a cost of £247 to £367 per m² for the supply and erection of closed panel kits.
- Assuming that the insulated closed panel kit supplied and erected accounts for 30-40% of the total build cost not including land cost this would suggest a total build cost of £1725-2300 per m². This is considerably higher than the proposed performance specification of £1250-£1500 per m².
- The effect of efficiency savings on the manufacture of components and the overall construction cost is however dramatic. A 10% decrease in labour costs reduces the total build cost per m² by 4% and a 10% decrease in material costs results in a 6% decrease. The proposed efficiency savings of 20% material cost and 40% labour cost however results in a reduction of 28% per m².
- It has not been possible to confirm within this study how realistic these proposed savings are, however based on greater knowledge of the processes and a study of common manufacturing systems related to pallet manufacture, these savings would seem to be attainable.

7 Based on a rate of £1.87 per linear metre for untreated homegrown 47 x 175mm C16 stated by E.Johnson of BSW.
Source: E. Johnson, *British Grown C16 Timber* (Newbridge: BSW Timber) p. 23.

9.09 SUMMARY OF FINDINGS

9.09.1 SUBSTRUCTURE

STUDY 1.1

What substructure options are compatible with the proposed components and ensure a minimal disturbance of potentially sensitive and challenging rural sites?

STUDY 1.1

- The steel foundation connector trialled in the studio would appear to suggest that a universal connector can provide an efficient interface with most foundation types. The geometry of the trialled connector permits a reasonable level of access to all fixings points when the frame is assembled.
- However the connector must be prefixed to the ground floor beam prior to its location on footings as the required coach screw fixings are too long to be accommodated between flanges. This places greater emphasis of the accuracy of the setting out of anchor bolts, as the set up allows very minimal adjustment.
- An analysis of foundation types would suggest that the system is ideally suited to pad and pile type footings.
- Pad and pile footings would seem to offer considerable opportunities to develop rural sites with challenging topographies without the requirement for significant earth movement. However this scenario has demonstrated that the resultant height and geometry of point load foundations in combination with a heavily sloping site has presented considerable construction challenges, included increased health and safety risks.

STUDY 1.2

How is a level threshold detail achieved whilst ensuring that the primary timber structure is protected to meet construction standards?

STUDY 1.2

- The level threshold detail poses perhaps the most challenging detail arrangement associated with the system. The studio has not provided a suitable context to assess alternative options in practice however a paper based study has identified a number of potential development routes which could be pursued further in collaboration with warranty providers.

9.09.2 PRIMARY STRUCTURE

STUDY 2.1

What is the most efficient method of setting out to ensure accuracy and reasonable tolerance for the assembly of the primary structure?

STUDY 2.1

- Setting out posed a considerable and time consuming element of the construction due to the absence of any fixed site point and professional positioning equipment. Point load foundations in conjunction with a steep site topography makes the setting out of a post and beam frame at a substantial height above ground, extremely challenging to initially set out and check to a good standard of accuracy.
- However Bay 2 and Bay 3 employed a preformed and assembled full scale rigid template, manufactured out of 18mm OSB, in order to accurately set

out the key elements of the primary structure, including the locations of the foundation anchor bolts. With anchor points marked, drilled and glued in location, there was very high confidence that the primary ground floor frame could be located and fixed in place with a good level of accuracy, with only vertical positioning requiring adjustment using packing pieces.

- Although attempts were made to employ the dimensional accuracy of the components themselves to essentially self set out, the result is entirely impractical due to the weight and scale of the combined components.
- Although unconventional, the use of a prefabricated primary structural template provides an efficient method of accurately simplifying the setting process, and enables the workforce to control quality with ease, particularly in the challenging context of point load footings.

STUDY 2.2

What is the most efficient assembly process to ensure that working at height is limited and demands on mechanical lifting equipment and scaffolding can be minimised?

STUDY 2.2

- The studio has tested the proposed assembly methods in a particularly challenging context. The height of the substructure footings above ground in combination with challenging site conditions, has posed many health and safety considerations throughout the process. The study has found however that the safest assembly process installs a ground floor ring beam of primary floor beams and spanning edge beams on foundation fixing points. Suspended timber floor open or closed infill panels are inserted into the structure and permanently installed to provide a robust working platform. Columns are installed and edge and tie beams located and fixed at intermediary floor and/or eaves levels. Working from a scaffolding tower or intermediary floor deck, roof trusses are then installed. The studio trials have shown that the installation of roof trusses can be significantly safer if installed as individual rafters coming together to meet at the ridge. It is proposed that the final ridge connector is then installed in situ, slotted through the upper or lower flange of the box section rafters and fixed in place. This proposed assembly process would ensure very limited requirement for mechanical lifting equipment and scaffolding, with a simple movable scaffolding tower providing a safe working environment for the majority of tasks.
- Trials with assembling portal frames at ground level and rotating up to vertical by hand were conclusively unsuccessful due to the weight and scale of components. If this approach were to applied to a larger scale of construction significant lifting equipment would be required, however the system could be considered quite exceptionally safe to assemble.

STUDY 2.3

What alternative solutions could be considered to provide an efficient, flexible and high capacity multi-direction structural junction?

STUDY 2.3

- In practice the existing primary structural connections perform very

effectively. A particularly valuable characteristic is the independent nature to primary floor beams and spanning edge beams permitted by these connectors. This arrangement enables primary floor beams to be located and adjusted for accuracy on foundation fixings prior to the installation of the spanning edge beams, which can be simply dropped into location and fixed.

- The shear plate connector does however pose some concerns regarding accuracy, as its location is not positively determined and is therefore prone to some inaccuracies. Minor inaccuracies in the positioning of the connector can generate significant discrepancies in the resultant structural opening and the fitting of infill panels.
- A multi directional steel node offers the most appropriate potential alternative to the current arrangement however it has not been possible to apply and test a resolved design within the scope of this study.
- Beyond efficient functionality it is evident that thermal performance is the most critical characteristic of the structural node and subsequently it is now essential to perform thermal modelling on alternative solutions to the model

9.09.3 SECONDARY STRUCTURE & THERMAL ENVELOPE

STUDY 3.1

- In the absence of a typical ground bearing slab, the installation of the ground floor primary structure and infill panels is essential to provide a robust working platform to work from. The height of the proposed structure above the existing ground floor level posed considerable challenges to the set up of a robust and useful scaffolding around the building perimeter. Once the suspended timber floor was constructed however, the majority of tasks could be conducted from within the structural envelope working from an easily manoeuvred scaffold tower.
- The post and beam primary structure acts as a robust framework against which panels can be propped or temporarily located without fixings. This significantly reduces the time spent by labourers bearing the weight of panels, specifically during the installation of fixings.
- The study has shown that components can be successfully applied in both an open panel and closed panel form. Both options offer significant reductions in working at height however in the majority of cases a limited amount of working at height is required to install fixings to the exterior. In all three roof sections, panels were designed with an external sheathing board applied during prefabrication. This ensures that there is a robust roof deck which can be safely employed to provide a work surface to complete

STUDY 3.1

What is the most efficient assembly process for infill panels, including levels of off site prefabrication, to ensure that working at height is limited and demands on mechanical lifting equipment and scaffolding can be minimised?

fixings from above. Typically panels are lifted from within the structural envelope and passed through the structural opening at an angle, righted and dropped down with external sheathing or joist hanger sitting atop the box section frame. This allows for all of the lifting to be performed from below without needing to extend significantly.

STUDY 3.2a

How can methods of prefabrication be standardised or mechanised to improve manufacturing efficiency in terms of cost, labour and quality?

STUDY 3.2b

What is the most efficient geometry of primary structure for the standardisation of infill panels, and what is the most efficient method of integrating racking resistance?

STUDY 3.2c

What approach should be taken to standardising roof pitches in order to promote the rationalisation of infill panels throughout the construction whilst enabling a good level of design flexibility?

STUDY 3.2

- A number of jig and assembly processes have been trialled alongside alternative infill panel geometries with varying degrees of success. It is challenging to conceive jigs that can combine improved quality control with assembly speed and flexibility in panel size. A width of 600mm has been adhered to throughout the construction which has enabled jig design to focus on enabling a number of panel lengths.
- This process has supported the feedback given by KJJ that overhanging OSB sheathing panels are very challenging to accommodate in an accurate prefabrication process.
- The closed panel with ladders and panels fixed to the very perimeter of accurately cut OSB sheathings is capable of being accurately manufactured without the assistance of an elaborate jig arrangement, as sheathings are employed as a self template for panel assembly.
- Although providing a much greater flexibility in panel size and geometry, the use of multiple layers of 9mm OSB to sheath panels both on and off site has proved to be unsuccessful. The poor stability and robustness of the panel significantly reduces the quality of the prefabricated system and limits the ability to develop further advanced panel types.
- The closed panel type as shown in drawings AC(2)102, AC(2)402 and AC(2)502, would appear to be the most efficient solution for construction. In this proposal, racking resistance is incorporated into the infill panel. Additional sole, head and bearing plates are fixed directly into the primary structure using appropriately robust fixings to transfer racking loads. The prefabricated infill panel is notched to the interior face of wall panels and the bottom face of roof and floor panels to accommodate sole, head and bearing plates. Fixings are then installed through the infill panel, passing through the external sheathing and an lateral panel plate to make a robust connection with the installed sole, head and bearing plates. If specified correctly with appropriate fixings it is believed that this junction should provide capacity to transfer diaphragm loads as at least a single sided OSB panel. The panel is entirely accommodated within the structural opening of the primary structure within a 600mm dimensional arrangement enabling a high level of standardisation and repetition and ensuring openings can be dimensionally coordinated without conflict.

- The provision of a loose tongue junction provides a connection between neighbouring panels that is surprisingly robust and ensures that standard generic panels can be made specific to locality without affecting manufacturing processes. This junction is unlikely to be considered structurally robust however as a conceptual arrangement it functions with considerable success.
- In review of these proposed panel arrangements, Burroughs have advised concerns regarding the jointing between panel plates and ladder beams. It is advised that the fixings installed into the endgrain of ladders and/or panel plates are unlikely to be calculated as sufficient under the Eurocode calculation methods due to the section size of the timbers and the required spacings between fixings. Therefore further work is required to establish a geometry, perhaps similar to that proposed in figure 9.87, which can increase the fixing area and increase the capacity of the panel joints, however it is considered that these developments could offer potential to ease fabrication further.

STUDY 3.3

Can homegrown timber components be combined with proprietary structural fixings to provide efficient solutions for junctions in a prefabricated component system?

STUDY 3.3

- Combining joist hangers with homegrown timber components are ideal for refurbishment work and new build housing where components are installed individually, with sheathing installed in situ. They provide a very quick method of installing a robust platform of joists, specifically, the use of top flange joist hangers, where the hangers can be simply dropped onto the primary structure. However they do not offer a suitable junction type for a panellised system of this type or scale. In addition, further work will need to be carried out with proprietary fixings in order to deliver ladder beam geometries alongside readily available hangers as the depth of the current primary and secondary structural members do not coincide with standard hanger dimensions.

STUDY 3.4a

What is the thermal performance of the proposed basic arrangement of construction components?

STUDY 3.4

- The study has shown that in most cases it is unlikely to be more efficient to integrate insulation into the manufacture of the prefabricated panel. The closed panel system is the only tested panel that has a geometry that would support the installation of natural insulation, specifically Warmcel, during prefabrication. The proposed geometry could be simply closed during prefabrication using a building paper or a rigid insulation board to provide an airtight container to receive the loose insulation. This geometry of panel would have areas of weakness that could be prone to damage during transport however the provision of internal and external sheathing boards ensures that these areas are minimal.

STUDY 3.4a

What are the effects of the thermal specification on the construction process and is there potential for the integration of insulation into prefabricated components?

- In discussion with Pen Y Coed Warmcel there would appear to be very few concerns associated with installing insulations on site, either blown damp into open panels or injected into closed panels. In the case of injected insulation, it is likely that each spacing between studs would need to be infilled independently to ensure that there are no voids however this is advised to be the typical installation method for timber frame construction.
- In comparison with the proposed performance specification given in Section 5.07, U values calculated from the proposed basic general arrangement are at the top end of the performance range identified for external wall and suspended ground floor elements however the pitched roof U value is currently above the range proposed in the specification.

9.09.4 OPENINGS

STUDY 4.1a

Can a prefabricated unit be employed to provide an interface between off the shelf windows and a dimensionally coordinated infill panel system?

STUDY 4.1b

How can standard window detailing be employed to ensure flexibility in window types and manufacturers, and ensure replacement windows can be fitted?

STUDY 4.1

- The study has generally found through detailed design that a prefabricated window cassette could be employed to provide an interface between off the shelf windows and the majority of panel types trialled. During construction, in the absence of any rigid window structure, infill panels had to be measured and propped in place whilst being fixed. This has resulted in a reduced accuracy of the structural opening in some areas. If a robust prefabricated unit was to be installed during panel installation it could potentially be employed to temporarily support and position above window panels during fixing ensuring the accuracy of the opening and making the process considerably more efficient.
- An attempt has been made to detail openings as ‘typical’ as possible to ensure that manufacturer’s recommended standard details can be followed as far as possible. In most panel designs this is successfully achieved with little limitation. Closed panel type 04 achieves a particularly successful detailed solution as the full depth of the structural opening is formed using robust solid section plates installed at head and sill providing good freedom for the employment of traditional robust window details.
- It is proposed therefore that a cassette window system is not essential to complete the detailed system however it could be of significant benefit. The proposed prefabricated window cassette is therefore considered as three independent elements, with an internal and external timber lining sandwiching a standard window frame. The separation of these elements is intended to offer the potential to reduce thermal bridging and permit the removal and replacement of the window during the building’s life. It is proposed that these three elements will require jointing internally and externally to minimise water ingress and ensure airtightness. It is feasible

that the window frame element could make use of standard off the shelf window units however the need to provide for jointing to the internal and external linings may limit the feasibility of this option.

- It is proposed that this study will be further investigated through the manufacture of system specific windows when funding is available.

STUDY 4.2

Can a prefabricated unit be employed to provide a level external door threshold and ensure flexibility for internal floor finishes?

STUDY 4.2

- Through detailed design a number of options have been considered for providing a level external door threshold. The provision of a floating floor, potentially integrated into the prefabrication of floor panels, provides a dimensional separation between the primary structure and the internal floor. This enables a much more flexible approach to the threshold detail as the floating floor depth can be tailored to the requirements of weatherproofing and incorporating a level threshold detail in addition to a much greater freedom over the selection of internal finishes. It is proposed however that this study is one which will require further review when considering the design of an NHBC compliant ground floor structure.

9.09.5 FINISHES & SERVICES

STUDY 5.1

What is the most efficient and appropriate method of integrating services into prefabricated panels?

STUDY 5.1

- The integration of services into open prefabricated panels can be relatively efficiently accomodated whilst internal sheathing boards are not in place. The Passive House has clearly demonstrated the difficulty associated with first fix when working with closed panels. A review of alternative advanced panel systems has found an increased use of pre-planned service ducts or plug and play systems incorporated into the manufactured panel. Whilst this is considered a potential solution, it will significantly complicate manufacture, introducing skills that are not currently associated with the existing manufacturing environments. It is also likely to significantly increase the cost of the system due to the small scale of the system components.
- However the primary limitation to the integration of services into the structural zone of the infill panel is the conflict when meeting the post and beam frame. In order for services to pass between structural bays by penetrating the post and beam frame, significant localised strengthening will be required.
- The Passive House has clearly demonstrated the success of a dedicated service zone constructed to the interior of the thermal and structural envelope. This has been reinforced through the consideration of alternative panel designs trialled in the Rural Studio. The proposed system of closed panels offers the potential to develop an advanced panel which includes

service zone battens and rigid insulation, installed offsite, combined with a traditional onsite approach to the installation of services, without causing any disruption of the structural envelope.

- As a suspended timber floor with a minimum ventilated void of 150mm below, it is possible for large services such as soil pipes to be distributed below the building piercing the thermal envelope at their required location. Smaller services however can be easily distributed within the floating floor zone, above the structural timber deck, making the inclusion of an underfloor heating system possible.

9.09.6 PROJECT EVALUATION

STUDY 6.1

- The studio has provided many useful findings regarding the labour requirements associated with the manufacture and assembly of system components. In can be generally concluded that the majority of manufacturing tasks can be safely and efficiently completed by individual labourers of varying skill and physical ability. However when at the scale of infill panels, additional assistance is required for manual handling.
- Construction tasks generally required more than one person to assemble, adjust and fix components due to the weights involved. However two people could generally complete the majority of tasks efficiently without requirements for significant machinery. The primary structure required the greatest input of personnel due to the weight and scale of components and the height of the work areas above ground. Once erected however the primary structure provided a robust support for the installation of infil panels thereby reducing the number of personnel required to install and support panels whilst being fixed.
- The study would suggest that the primary structure could be effectively set out, assembled, adjusted and fixed in a period of 2 to 4 days on prepared footings if all components are fully prefabricated.
- If manufactured as the proposed system of closed panels, infill panels with internal and external sheathings and potential for the offsite inclusion of insulation, could be installed in approximately one week.

STUDY 6.2

- Once combined as a full insulated structure including floors, walls and roof a total cost of £690.13 per m² is estimated. Extrapolating based on a timber frame cosy of approximately 30 - 40% this would suggest a total build cost of £1725-2300 per m². This is considerably higher than the proposed performance specification of £1250-£1500 per m².

STUDY 6.1a

How long does it take to build domestic scale structures using homegrown timber components?

STUDY 6.1b

What are the minimum labour requirements to ensure a safe and efficient construction process?

STUDY 6.2

What does it cost to manufacture and build using homegrown timber components and what options are there for reducing costs?

- However the improved knowledge of the involved manufacturing and construction processes and associated costs, in combination with a detailed study of appropriate manufacturing systems has provided great confidence that there are significant savings to be made if economies of scale can be realised.

9.09.7 IN SUMMARY

In this chapter a series of research studies have been proposed to test and refine a homegrown timber construction system for self build housing, with three objectives;

- to test and develop construction processes using a system of homegrown timber components for ease and buildable simplicity as a self build rural housing solution,
- to develop low intensity manufacturing processes appropriate to the existing timber processing industries of Wales,
- to refine a system of homegrown timber components as a whole house construction system to meet the performance specification identified in Chapter 5.0.

The investigation has been severely affected by extreme climatic conditions. Consequently, a number of potential opportunities for efficient construction processes were omitted or considered only as paper based studies, to ensure safety was maintained as the priority. In addition, due to the limited funds and time available for the construction, some ambitions had to be curtailed in order to focus on priority investigations to meet the objectives identified above.

However, based on these findings, it is possible to draw conclusions on the appropriateness of a homegrown timber construction system for the self build construction of affordable homes.

Chapter 10.0

Conclusion

10.01 SUMMARY OF FINDINGS

In this chapter, the results of design and construction studies are summarised in order to inform the hypothesis;

Homegrown softwoods can be re-engineered using low technology and low intensity manufacturing processes to provide a self build affordable rural housing solution.

In Chapter 4.0, a research methodology proposed a series of design studies to inform the development of a whole house construction solution using homegrown timber components. This includes;

- Prototype testing and development of homegrown timber components
- Design Pattern Book of House Types
- Prototypical Construction Studies

These studies have considered a matrix of research outcomes set out in the form of a development framework, and categorised against a Performance Specification for affordable rural housing.

The final element of this has focused on a direct investigation into the use of homegrown timber components as a method of self build construction for affordable housing, with the construction of a full scale prototype building.

From these investigations, the following findings can be summarised;

10.01.1 AFFORDABLE HOUSING FOR RURAL WALES

There is an acute need for additional affordable housing units in rural Wales. National policy has looked to address this need during the period of this research study with the delivery of an additional 6,500 affordable homes. However there remains significant concerns regarding the long term sustainable delivery of affordable housing in rural Wales, due to a number of physical, social and economic barriers that are specific to the context of rural Wales.

The house building industry in the UK is heavily reliant on a small number of large, commercially driven volume housebuilders. Mechanisms for delivering affordable homes are subsequently tailored to this context, typically through the commitment of financial or other contributions, obligated through Section 106 agreements. Consequently, the delivery of affordable housing is highly susceptible to commercial interests and the economic environment. However, there is considerable international precedent for alternative and radical delivery methods, including the facilitation of self build as a significant contributor. By building on existing planning mechanisms such as Community Land Trusts, Rural Exception Sites and Rural Housing Enablers it may be possible to deliver affordable housing through alternative delivery means. One example is the

enabling of community self build affordable housing schemes by providing those with greatest need, with land, training and support to build their own homes, independent of the commercial constraints of a volume house builder.

10.01.2 HOMEGROWN TIMBER IN CONSTRUCTION

The study has found that homegrown timber can be employed in standard timber frame panel construction, however it is rarely used due to concerns over reduced quality, an increased propensity to distort, and the common over specification of structural timber by consultants, which results in the exclusion of homegrown timber resources. Due to the availability, quality and cost of imported timber, a study performed by BRE finds that it is unlikely that the case for greater use of homegrown timber in construction can be dramatically improved without taking a radical and innovative approach to construction methods and components. These findings have been comprehensively reinforced by personal experience during the project period.

Sitka Spruce is the predominant production crop of the Welsh forests and typically displays the most challenging characteristics of the homegrown softwoods for construction purposes. It is currently employed for a number of useful, but typically low value products including pallets and packaging material and is readily available as C16 carcassing timber. The forest industry is the most valuable industry in Wales, however it requires considerable subsidy to maintain and improve the quality of its products. It is proposed therefore that in order to encourage investment and the sustainable growth of homegrown resources, alternative outputs should be identified to increase the value of the industry at all stages of the supply chain.

Over the past two decades, political interest in Modern Methods of Construction has grown following a number of significant studies into the nature and performance of the construction industry. It is generally concluded that the primary mechanism for delivering better quality housing in higher numbers at lower cost is to encourage a construction industry which develops and applies Modern Methods of Construction. It is therefore proposed that an innovative MMC could apply homegrown timber resources to the specific application of affordable housing for rural Wales. A system which is tailored specifically to the available Welsh resource, and makes use of low intensity and low technology manufacturing processes appropriate to the existing Welsh industries, could offer a construction solution which encourages and enables the growth of self build as a major contributor to affordable housing delivery.

10.01.3 AFFORDABLE HOUSING USING HOMEGROWN TIMBER

The study has subsequently employed a number of design based investigations to develop and test an approach to construction which applies homegrown timber components in a manner appropriate to the context of affordable rural housing. These investigations have been tested against a performance specification, designed to meet the current market demands for affordable housing standards and ensure that the approach remains appropriate for a reasonable future life.

The specification has been aligned with a matrix of studies, and it is against this matrix, as shown in Section 4.03, that the results of the study can be briefly summarised;

COMPONENT DESIGN AND CERTIFICATION

The study has identified, tested, developed and applied a number of homegrown timber based components. Through the design and construction of prototypical studies these components have been employed individually and in combination for use in a broad variety of construction scenarios, with varying degrees of tested certification.

It can be generally concluded that homegrown engineered timber components, as identified in Chapter 5.0, can be considered fit for purpose for the specific application of house construction. However, the certification of components is currently limited to specific system arrangements. The general application of these components therefore remains quite restricted. Further testing is required to extend the certification of homegrown timber components and homegrown timber-based systems to enable greater flexibility and ease of application.

In terms of component design, the greatest restriction to this study has been caused by the tested permissible spans of engineered components in the form of ladder beams. In both Type 01 and Type 02 form, the secondary structural components remain insufficient to realise the proposed spans required by designing to Space Standards. Based on the design of a pattern book of room and house types, it is proposed that further detailed testing should target a minimum span of 3.3 - 3.6m in order to enable the design of flexible, standard compliant room geometries.

BUILDING DESIGN

The Pattern Book of House Types developed in Chapter 7.0 demonstrates the flexibility of the proposed construction system to enable a wide variety of house types. In addition, it is believed that this paper based design study, in conjunction with the prototypical construction studies, have demonstrated the applicability and adaptability of the system to the context of rural Wales.

When considering house design there is often an atectonic approach taken



Figure 10.1: Four semi detached Ty Unnos Modular affordable housing units have been constructed at Dolwyddelan, in the Snowdonia National Park, with planning requirements for slate and timber cladding.
Source : H. McAteer, <www.dolwyddelan.org>

whereby the systems utilised in its construction are disguised in its realised expression through the use of claddings and linings. It is possible to employ this approach with the proposed system of components, as displayed by requirement in the construction of the Ty Unnos Modular units at Dolwyddelan, shown in figure 10.8. However, the system also offers great opportunity for a tectonic approach to house design, with the technologies and assembly clearly evident in the realised construction. Personally this is considered highly appropriate to the context of rural Wales with local skills and resources, and simple technological arrangements displayed as ornament in search of a new vernacular.

DETAILED DESIGN

The resolved system of components is summarised in Table 10.1. Generally it can be concluded that these detailed components have the potential to realise a simple and buildable construction system, appropriate to the proposed application. Based on this design it should be possible to realise;

- Multi-storey post and beam structures up to 2-3 storeys,
- With internal spans of up to 3.0m by 4.8m,
- For attached and detached constructions.
- A performance specification approximately equivalent to that proposed in Chapter 5.0, with reasonable flexibility to adapt components and construction detailing to achieve increased performance specifications.

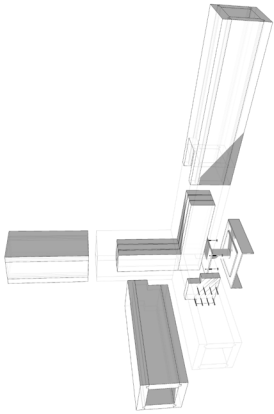
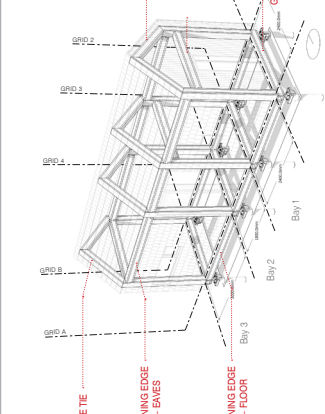
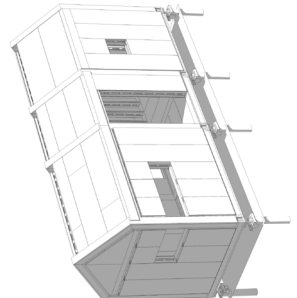
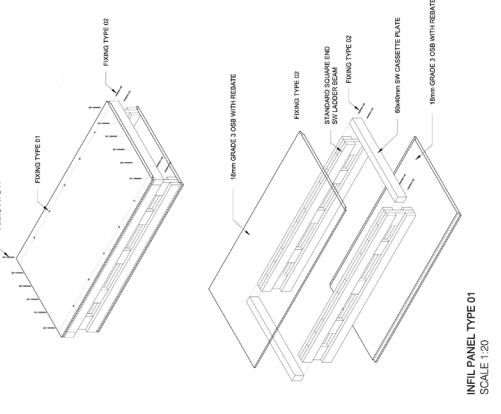
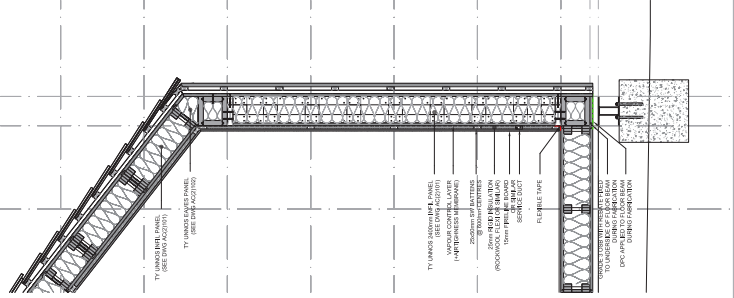
There remains a number of unresolved factors as summarised in Table 10.1, perhaps the most critical of these, however, is the proposed system’s compliance with warranty required construction standards;

WARRANTY AND NATIONAL BUILDING STANDARDS

It has not been possible to confirm the detailed design of the proposed construction system as an acceptable standard for warranty providers such as the NHBC. There are limited concerns regarding the ratification of the system under National Building Control. However, there remains a significant conflict with the use of structural timber within close proximity to the ground, as proposed with the design of a suspended timber floor construction.

This incompatibility with construction standards offers perhaps the greatest challenge remaining for the detailed design of the construction system. However it would seem to be inconceivable in the existing context of emerging construction technologies, that this scenario can not be suitably resolved in collaboration with an appropriate warranty provider. The experience of this study has demonstrated that there is a concerning potential for existing warranty standards to severely restrict the development of modern and innovative methods of construction.

Table 10.1: Summary of resolved detailed design proposals

CONSTRUCTION ELEMENT	RESOLVED SOLUTION
Substructure	<p>A common foundation connector ensures that an entirely flexible approach to substructure can be maintained to ensure adaptation to a broad variety of site and geological conditions.</p> <p>It is considered that in some cases the replacement of the ground floor primary structure and suspended timber infill floor with a ground bearing slab is likely to be appropriate and it is with ease that the system of components has been proven to adapt to this scenario.</p>
Primary Structure	  <p>A hollow box section of Sitka Spruce is combined on site using laminated timber connectors, or rectangular steel section multi-direction connectors to realise a post and beam frame with capacity for up to 3 storeys. The primary structure with integrated roof trusses provides a framework into which a dimensionally coordinated system of standardised thermal infill panels and doors and windows is installed.</p>
Secondary Structure	  <p>The proposed system of secondary structural components, tested and resolved through the construction of the rural studio, is a system of closed panels comprising an external and internal sheathing of 18mm OSB sandwiching homegrown timber ladder beams.</p> <p>The system employs a dimensional coordination set out with a 600mm base dimension in plan and section, determined through the design of a pattern book of room and house types which combines design flexibility with material efficiency and proposes a system of components that in the most part can be manually handled by 2 - 3 individuals.</p> <p>The design of infill panels has the potential to evolve to efficiently include further advanced prefabrication including the off site installation of Warmcel insulation and internal battening, insulating and ducting for services.</p> <p>The detailed design of the closed panel is proposed as a conceptual approach to the design of the system illustrating the geometry and systems required to enable a buildable system of components within the context of this application. The study has generated a number of limitations that remain with this approach, most notably regarding the provision of robust junctions into endgrain timber and the suitable provision of diaphragm connections. However it is proposed that within this proposed arrangement there is the potential for further development to resolve these details in collaboration with structural consultants.</p>
Thermal Envelope	 <p>Components have been tested against stringent performance specifications and achieved significant success. There remains some concerns regarding the compromise of the thermal envelope at node points caused by solid timber or steel connectors. It is considered essential that further work be carried out to model the existing junctions in the system, and further design invested in their improvement as required.</p> <p>However the studies have demonstrated that the performance standards identified in Chapter 5.0 are feasible using the proposed system of components. The proposed geometry of the structural envelope has been approximately calculated to give U-values of 0.13 W/(m2k) for suspended timber floor, 0.19 W/(m2k) for walls, and 0.2 W/(m2k) for a pitched roof. These do not meet the performance standard identified in Chapter 5.0, however the study has shown that there is great scope for adjusting the depth of infill panels to suit the insulation requirements of given projects. However in the Welsh Passive House, an alternative solution has demonstrated that the system is highly compatible with an external overcladding of insulation, which enables the system to be efficiently tailored to even the highest of performance standards.</p>
Services	<p>Design and construction studies have demonstrated that the most efficient solution to service distribution is to enable it to occur independent of the system components. This is achieved by incorporating a service zone to all internal surfaces.</p> <p>Although this solution causes further layering of complexity to the building envelope, there is great potential for the required elements to be incorporated in to the prefabrication of elements. In addition to reducing conflicts with prefabricated components, the solution most critically enables the system to be fully assembled as a weathertight insulated envelop prior to first fix. This is considered particular valuable as it allows for self builders to realise all components of the system without introducing skilled tasks such as plumbing and electrics at inconvenient points in the construction programme.</p>

MANUFACTURE

The manufacture of components has significantly developed throughout the research period, adapting to new applications, and evolving in response to detailed findings.

The manufacture of components for the Rural Studio has demonstrated that in the main, system components can be manufactured with reasonable efficiency in a 'typical' prototyping workshop with limited demands for additional tooling or skills. The process has developed a number of effective mechanisms to improve the efficiency for the manufacture of repeated elements including a table for ladder beam manufacture and press for the manufacture of box section beams. These have been realised at limited capital expense, utilising readily available machinery and materials, and could be simplified further to reduce costs.

Alongside this study however, components have been employed by other members of the Project Team to deliver a greater scale of manufacture. The scaling of manufacture to much higher quantities has been relatively efficient and has typically been facilitated by diversifying the use of existing facilities and resources. The manufacture of components is found to be at its most efficient in terms of material waste, when multiple scales of components are manufactured in parallel. This enables relatively high proportions of material to be rejected at large component scales and recycled for use in smaller by products.

Based on these findings, it is not a recommendation of this study that the proposed components are appropriate for manufacture in the manner displayed for the Rural Studio. The studio has shown that it is feasible to adopt homegrown timber components at this limited scale of manufacturing, allowing for individuals to potentially manufacture as well as construct their own home. However, this can not be seen to be recommended as an efficient investment of time and effort. It remains significantly more economic to consider components to be manufactured in larger quantities by dedicated manufacturers, with self builders applying sweat equity to the onsite construction of prefabricated components.

The approval of manufacturing processes for completion of ETAG approvals has proved to be laborious and required a significant investment in time, specifically to ensure the required level of quality control. It is this level of detailed assurances, required by product certification, that is likely to place the greatest restriction on uptake by other potential manufacturers in the future. Without the support of a funded research project and investment from highly ambitious and motivated individuals, it is likely that the requirements of this component certification process would have overwhelmed individual commercial parties and significantly reduced the viability of the project.

However, in the course of the study, members of the forest industries have

generally responded favourably to the processes involved in the manufacture of proposed components. With certifications available for their production and sale, it can be concluded that there is great potential for the manufacture of components at a variety of scales, from the hand-made small numbers required for a single unit, to the high volume production of standardised components.

CONSTRUCTION / BUILDABILITY

The study has demonstrated, at a number of skill levels, the potential for construction efficiency offered by the proposed construction components and their assembly processes. The system offers an innovative and radical approach to construction which is a significant divergence from typical timber frame construction. Subsequently a number of limitations remain that would suggest that the proposed system of components is unlikely to significantly challenge existing systems on the market. However, when applied to the context of small scale development opportunities, the system offers great potential for use by relatively low skilled individuals as a self build construction system. This is encouraged by a number of unique qualities;

- The weight and detailed design of components, designed to a 600mm grid, are appropriate for manual handling, significantly reducing the need for mechanical lifting equipment.
- The design of the system and assembly method offers potential to reduce health and safety concerns, as working at height and other high risk scenarios can be significantly limited.
- Specialist construction skills such as mechanical and electrical installation can be programmed as autonomous work packages to be contracted out if necessary.
- There is potential for all wet trades to be excluded from the construction, including foundation design and internal finishes.
- Assembly methods make use of largely typical DIY skills and tools, with most construction processes simply employing an electric screwdriver.
- A high degree of quality can be easily achieved during setting out and assembly with the use of simple templates, and the construction components themselves.

The speed of construction demonstrated in the Prototypical Studies and Rural Studio study suggest that it is possible to realise site build programmes that are at least comparable to those achieved using standard timber frame construction.

ECONOMIC PROFILE

It has not been possible, through the development of this research study, to accurately and comprehensively determine the economic efficiency of the proposed system of components.

Based on the findings of Prototypical Studies and the construction of the Rural Studio, it can be concluded that the system is beyond the range of build costs that were considered to be affordable in Chapter 5.0. Although material costs are relatively low compared with utilising solid section or glue laminated alternatives, labour costs required to assemble components are prohibitively high.

It is likely that costs determined in the construction of the Rural Studio are not a fair reflection of manufacturing costs, but findings from the Prototypical Studies suggest the cost of individual engineered components are not currently economically comparable with alternative components such as JJI joists and Posi Joists.

However there is considerable disparity between the findings of this research study and the economic viability of the commercially applied Ty Unnos Modular construction system manufactured by Kenton Jones Joinery and assembled by Elements Europe. Brief analysis of the realised construction costs using Ty Unnos Modular displays a significant saving over the Welsh Passive House, which essentially applies the same manufacturing and construction technologies. It is not clear where this disparity originates, but clearly the 'bespoke' nature of these projects is a significant contributing factor.

Based on the findings of the Passive House and the Rural Studio, an approximation would suggest that the cost of the manufactured building kit needs to be reduced by up to 40% in order to make it a competitive system for affordable housing.

There is sufficient evidence to suggest that this is feasible, based on the achievements of the commercial partners, and the opportunities that remain for the realisation of valuable economies of scale. The proposed system of components has the potential to offer a great deal of repetition due to the rigid standardisation of components to an efficient dimensional organisation. If high capacity manufacturing systems were to be employed, such as those utilised by the pallet making industry, it is realistic to expect a significant reduction in manufacturing costs, and it is feasible that components will achieve competitive market values.

In addition, the Rural Studio has demonstrated the potential value of sweat equity in the delivery of affordable housing using the construction system. All elements of the manufacture and construction of the system have been proved to offer potential for relatively unskilled individuals to take an active role in the delivery

of affordable housing units, thereby contributing a valuable resource of labour, without the need for considerable investment in training and manufacturing facilities.

The economic findings of this study remain incomplete and subsequently inconclusive. It is evident that this is a significant limitation to the resolution of the identified research objectives and requires further work to accurately identify the commercial reality of the proposals.

10.02 IN CONCLUSION

In this study, I have endeavoured to conclude a detailed and challenging original hypothesis which I believe remains both current and extremely valuable for the future of the Welsh construction industries and rural communities. The nature of the study and its objectives have benefitted significantly, and likely could not have been examined in such depth, without the collective support and interest of a collaborative commercial and academic research team. This has however often provided considerable deflection from the original specific aims of this research study, and subsequently, the testing of this hypothesis has not followed a simple linear progression. This is evident in the length and number of findings identified in this dissertation.

The preceding summary of findings has illustrated that despite the complexity and depth of this interrogation, there remains a broad number of detailed limitations associated with the use of homegrown timber components for the construction of affordable rural housing. Perhaps most significantly, the economic viability of the proposed system of components. However the study has also demonstrated the significance of this application for homegrown timber and the Welsh industries, offering great potential for integration and sustainable adaptation of existing processes, skills and businesses to expand into the extremely valuable industry of the construction sector.

The study has focused on the well published need for additional affordable housing in the rural communities of Wales. It is unquestionable that this need is acute and despite recent political commitment, it requires continued focused investment to address an issue which extends far beyond providing dwellings in a sustainable and affordable manner, to address significant economic and social concerns in the communities of rural Wales. The specificity of affordable rural housing has significantly, although often surreptitiously, defined the development of this research study. Within this context, the outcomes of the study have demonstrated that the system of homegrown timber components has the potential to offer not just an alternative technology for the construction of affordable housing but also a radical approach to its realisation. It offers the potential to employ local skills and resources in manufacturing, and through careful and sensitive consideration of construction processes, it offers the potential to enable unskilled and low skilled individuals to contribute, in significant fashion, to the construction of homes. There is significant and successful, national and international precedent for the use of self build construction to deliver homes, in parallel to commercial developer house builders. This radical approach offers not just the provision of additional affordable housing units in areas of greatest need, but provides an opportunity to directly address acute social issues through the extension of valuable and applicable skills.

I believe this research has demonstrated, that through the application of low technology and low intensity manufacturing processes, a readily available resource of homegrown timber can be utilised in an innovative whole house construction system to offer a self build solution for the construction of affordable housing in rural Wales.

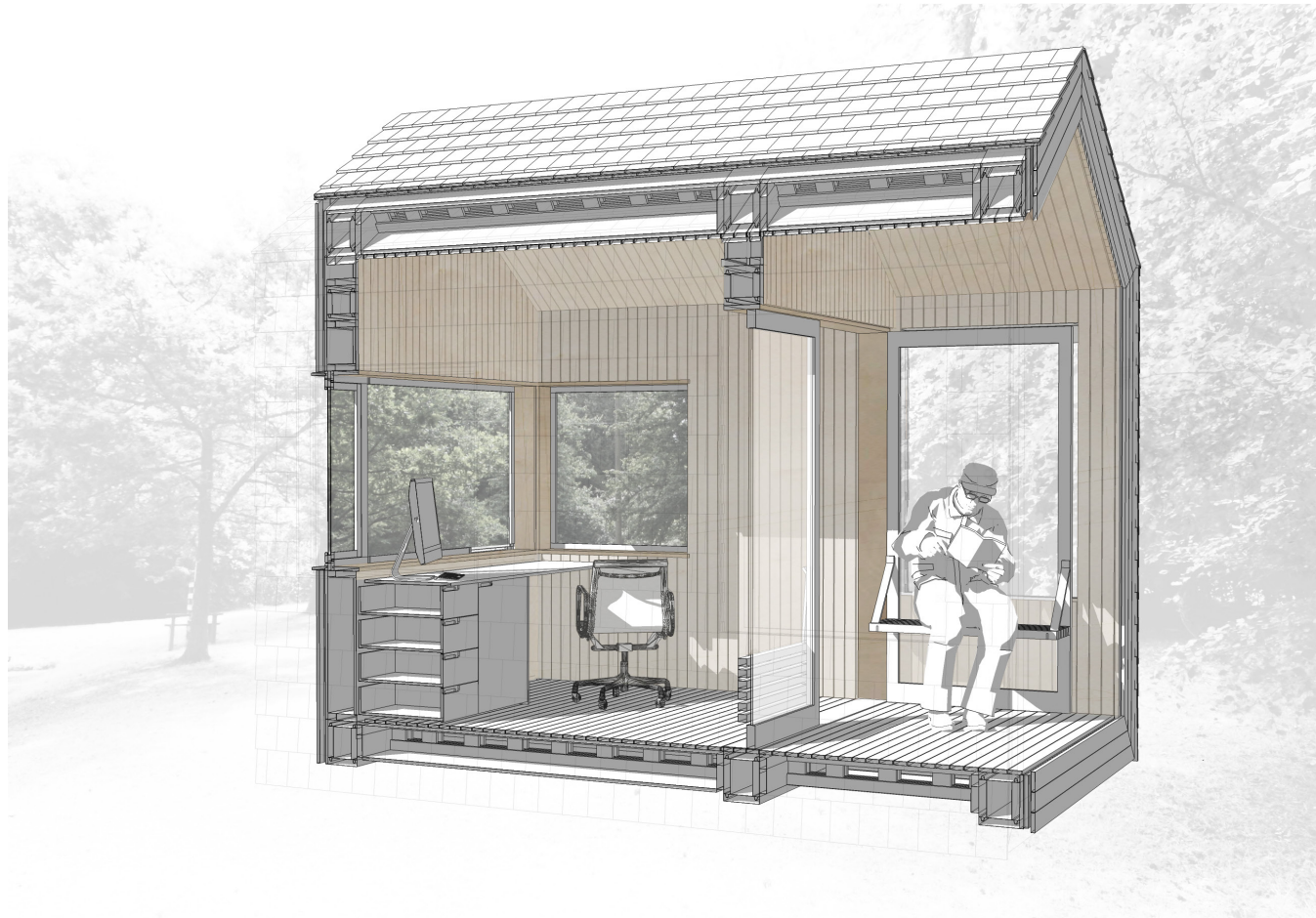


Figure 10.2: The Caban Unnos proposal is a small autonomous work space designed as a self assembly unit.

Figure 10.3: The structure was employed for a number of interactive demonstrations enabling a variety of organisations and interested groups to take part in its assembly.

Figure 10.4: The system of closed infill panels draws heavily on the detailing of the Rural Studio.

Figure 10.5: The structure being assembled for the Pembrokeshire Show.

10.03 POST SCRIPT

Following the completion of the Rural Studio, the Project Team have been invited to apply the research findings to a number of additional projects. This includes a construction based education program focused on the Ty Unnos system, funded by the Sustainable Development Fund. The program was proposed as a method of raising awareness of the value of homegrown timber for construction in Wales and specifically to demonstrate the Ty Unnos construction components and assembly method. Drawing from the findings of the Studio project, a small structure was proposed combining a post and beam single storey frame with a system of closed panels using Type 02 ladder beams. The structure, conceived as a Caban or small office unit has been transported across Pembrokeshire for a program of events throughout 2011.

The project has provided the useful opportunity to further the findings of the Rural Studio by offering an immediate application for the proposed system of components. The Studio has been manufactured and assembled by KJJ, using the proposed closed panel system and box section frame with multi-directional steel hollow section connector, employing slightly evolved detailing to that suggested and developed in the course of the Rural Studio study. This has enabled a detailed review of the commercial manufacture of the proposed system of components and additional assessments of the buildability of this assembly method. In addition to providing further funding to continue this development process, the project has been a particularly useful opportunity to assess the dissemination of the proposed system and the response from manufacturers, consultants, and potential self builders.

In response, a number of key observations have been generated from the Caban Unnos project;

- The system as it currently stands in detail is not appropriate for the construction of multi storey constructions. There are a number of concerns identified by structural engineers that will require further design, calculation and testing in order to develop the panel junctions to a standard where they satisfactorily meet the requirements of the Eurocodes in order to suitably provide racking resistance and robustness. Of particular further consideration is the design of junctions made between ladders and lateral plates which require junctions formed into endgrain.
- The Caban has demonstrated a lack of sufficient robustness of the current floor panel construction, due primarily to the stiffness of the tested Type 02 ladder beam. Performance testing has demonstrated a permissible span of up to 2.4m for these ladder designs which are simply not useful for the construction of housing to meet Space Standards, and this lack of capacity



Figure 10.6: The single storey 3 bedroom detached dwelling.

Figure 10.7: Entrance hall and circulation zone, lined with clear glazed rooflights.

Figure 10.8: The main living rooms with floor to ceiling openings.

Source : Robbie Meade, <www.robbiemeade.com>

is evident in the Caban study, whereby panels display a concerning level of distortion under load.

Most recently, the system components have been applied in a slightly altered prefabricated arrangement for the construction of a single storey rural dwelling. The construction of the detached dwelling, on an agricultural site, employed local skills and resources throughout, often employing labour and skills from agricultural and rural industries. The 140 sqm single storey, flat roofed post and beam frame with prefabricated open infill panels using Type 01 Ladder Beams took approximately 4 days to construct at a cost of approximately £250 per sqm. See figures 10.6 - 10.8.

The project is a further example that when applied in an appropriate context, the cost and efficiencies of the system can offer a competitive market alternative. Of particular note is the positive attitude taken by the planning department and the client towards the construction of essential housing on a rural site using local skills and resources.

In addition to these realised construction projects, the Project Team have been involved in detailed discussions regarding the transfer of technologies with alternative sustainable construction systems, including Modcell and RuralZed. These discussions are ongoing, and offer great potential for the further application of homegrown timber components. Of particular interest in these discussions is the perceived competitiveness of the commercially manufactured homegrown timber components when compared with existing imported construction components, including large section glue laminated frames. This suggests that there remains considerable disparity between the commercial reality of homegrown timber components and the available findings of this research study.

10.04 RECOMMENDATIONS FOR FUTURE RESEARCH

The research methodology employed in this study, including the Rural Studio and Pembrokeshire Caban Unnos, has provided a number of valuable research findings that have been, and are being, employed by the project team to further the development of the homegrown timber components. However there are a number of studies that have not been within the scope of this study that I feel would be extremely beneficial to complete my research.

01. MARKET RESEARCH STUDY

I believe that in order to identify the potential of the components, both as individual engineered timber components for structural applications and as a timber building kit, a full market research study needs to be performed. This study will need to identify; the economic profile of competitor products; the potential scale of demand; the supply chain including specifiers and suppliers in order to develop a better understanding of the sourcing requirements of the construction industry; potential barriers and opportunities for new products such as long term supply contracts and framework agreements.

02. THERMAL MODELLING

During the construction of the building studies, in order to calculate the thermal performance of the system for the purpose of SAP for example, it has been necessary to adopt standard applied values for areas of the construction, specifically thermal bridging at structural nodes. In general it is assumed that these standard values are conservative and therefore they will tend to underrate the thermal performance of the system.

Understanding the ‘actual’ thermal performance of the homegrown timber components is essential to the future development of component detailing and achieving high thermal performance standards. It is important that modelling is performed by an accredited modeller in order for the findings to be applicable with calculation procedures such as SAP, therefore the majority of the study would be performed by others. However, a valuable aspect of this study would be the development and testing of alternative detailed solutions. It is essential therefore, that the study is performed as a collaboration.

03. NATIONAL HOUSE BUILDING COUNCIL STANDARDS

The research study has clearly identified that in order for a new system of house construction to be adopted generally by the industry and homeowners it must be compliant with the NHBC Standard. As a system of timber components there are a number of areas of detail that are currently in conflict with the standard construction details defined by the NHBC. It has not been possible to resolve these issues within the scope of this study however through the design of building studies a large number of options have been identified and trialled. A further

study would extend this to engage the NHBC in the development of compliant details.

04. ECONOMIC ASSESSMENT

A fundamental factor governing the use of homegrown timber in the construction industry is cost. The study has provided considerable economic data to guide the design and development of timber components and allow commercial partners to identify potential markets. However it has not been possible to develop a full economic analysis of the system including assessing the potential manufacturing efficiencies associated with economies of scale.

In conjunction with a market research study a detailed economic assessment of the homegrown timber components and system is essential in order to assess the commercial viability of the proposed homegrown timber components.

05. AFFORDABLE HOUSING TRIAL

From the beginning of the study it was my hope for the research to culminate in the system being applied for the construction of an affordable housing scheme preferably in the form of a community self build. Although preliminary conversations with a number of parties throughout the project have suggested that this might indeed be possible it is certainly far beyond the scope of this PhD study. The study would further the findings of the building studies by providing further data, specifically in terms of economic profile. But most significantly the project would provide an opportunity to test the system's appropriateness for self build construction in terms of; the construction process specifically the development of skills and dissemination of information; partnering with communities and housing associations; economies of scale; and generally the response of all parties to the process and housing in use.

GLOSSARY OF TERMS

The Project Team - Refers to all members of the team involved in the development of the Ty Unnos construction system and research study, including;

Burroughs Engineering and Project Management - Burroughs

Coed Cymru - CC

Design Research Unit Wales - DRUw

Kenton Jones Joinery - KJJ

Gordon Cowley Timberwork - CT

Pontrilas Timber - PT

ORGANISATIONS + BODIES

Engineering and Physical Sciences Research Council - EPSRC

European Organisation of Technical Approvals - EOTA

Forestry Commission Wales - FCW

Housing Association - HA

Joseph Rowntree Foundation - JRF

Registered Social Landlord - RSL

Timber Research and Development Association - TRADA

Welsh Assembly Government - WAG

Wood Knowledge Wales - WKW

Welsh School of Architecture - WSA

MATERIALS + COMPONENTS

Oriented Strand Board - OSB

James Jones Joists - JJI

Structurally Insulated Panels - SIPs

European Technical Approval - ETA

European Technical Approval Guideline - ETA

BIBLIOGRAPHY

CHAPTER 1.0 INTRODUCTION

Design Research Unit Wales + Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Welsh School of Architecture, 2007)

Design Research Unit Wales + Coed Cymru, *Technology Strategy Board : Components and Materials for Low Carbon Buildings : Full Stage Application Form* (Cardiff: Welsh School of Architecture, 2008)

Jaakko Poyry Consulting, *Welsh Forest Industry - Mapping and Benchmarking the Forest Industry – Final Report* (London: Jaakko Poyry Consulting, 2004)

Jaakko Poyry Consulting, *Welsh Forest Industry - Mapping and Benchmarking the Forest Industry – Executive Summary* (London: Jaakko Poyry Consulting, 2004)

Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008)

CHAPTER 2.0 AFFORDABLE HOUSING FOR RURAL WALES

Affordable Housing Task and Finish Group, *Affordable Task and Finish Group : Report to the Deputy Minister for Housing* (Cardiff: Welsh Assembly Government, 2008)

Cook, Helen, *Delivering Rural Affordable Housing : WAG Seminar on housing planning policy* (presentation, 2009)

Conwy County Borough Council, *Conwy Deposit Local Development Plan 2007-2022* (Conwy: Conwy County Borough Council, 2011)

Flint, John, and others, *Delivering Affordable Housing in Rural Wales : Emerging Findings from a Current Research Study* (Sheffield: Centre for Regional Economic and Social Research Sheffield Hallam University, 2009)

Flint, John, and others, *A Study to Examine Local Barriers to the Delivery of Affordable Housing in Rural Wales : A Report to the Welsh Assembly Government* (Sheffield: Centre for Regional Economic and Social Research Sheffield Hallam University, 2009)

Home Builders Federation, *Callcutt Review Of Housebuilding Delivery : Submission By Home Builders Federation (HBF)* (London: Home Builders Federation, 2007)

Joseph Rowntree Foundation, *Rural Housing in Wales: Final Report* (York: Joseph Rowntree Foundation, 2008)

Kitchen, L., and Paul Milbourne, *Housing Need in rural Wales : towards sustainable solutions* (Cardiff: Wales Rural Observatory, 2006)

Land for Good, *Community Land Trusts: capturing land values for communities.* (Oswestry: Land for Good, 2010)

National Assembly for Wales, *Better Homes for People in Wales : A National Housing Strategy for Wales* (Cardiff: National Assembly for Wales, 2001)

National Assembly for Wales, *Members’ Research Service : Quick Guide : Community Land Trusts* (Cardiff: National Assembly for Wales, 2010)

National Self Build Association, *Self Build as a volume house building solution* (London: National Self Build Association, 2008)

National Self Build Association, *An Action Plan to Promote the Growth of Self Build Housing* (London: National Self Build Association, 2011)

Rowley, Steven, and others, *Wales Planning Research Programme : The Use and Value of Planning Obligations in Wales* (Cardiff: Welsh Assembly Government, 2007)

Statistics for Wales, *Statistical Bulletin 38/2010 : Affordable Housing Provision in Wales, 2007-08 and 2008-09* (Cardiff: Welsh Assembly Government, 2010)

Welsh Assembly Government, *Better Homes for People in Wales : A National Housing Strategy for Wales* (Cardiff: Welsh Assembly Government, 2005)

Welsh Assembly Government, *The Role of the Housing System in Rural Wales* (Cardiff: Welsh Assembly Government, 2005)

Welsh Assembly Government, *Local Housing Market Assessment Guide* (Cardiff: Welsh Assembly Government, 2006)

Welsh Assembly Government, *Planning Policy Wales: Technical Advice Note 2: Planning And Affordable Housing* (Cardiff: Welsh Assembly Government, 2006)

Welsh Assembly Government, *The Affordable Housing Toolkit* (Cardiff: Welsh Assembly Government, 2006)

Welsh Assembly Government, *One Wales: a Progressive Agenda for the Government of Wales* (Cardiff: Welsh Assembly Government, 2007)

Welsh Assembly Government, *One Wales Delivery Plan 2007-2011* (Cardiff: Welsh Assembly Government, 2007)

Welsh Assembly Government, *The Use and Value of Planning Obligations in Wales* (Cardiff: Welsh Assembly Government, 2007)

Welsh Assembly Government, and others, *Planning : Delivering Affordable Housing : Report of Welsh Assembly Government Seminars held in May 2007* (Cardiff: Welsh Assembly Government, 2007)

Welsh Assembly Government, *Delivering affordable housing using section 106 agreements: Practice Guidance* (Cardiff: Welsh Assembly Government, 2008)

Welsh Assembly Government, *Sustainable Homes : A National Housing Strategy for Wales* (Cardiff: Welsh Assembly Government, 2009)

Welsh Assembly Government, *Affordable Housing Delivery Statements 2007 - 2011 : Final Guidance* (Cardiff: Welsh Assembly Government, 2009)

Welsh Assembly Government, *Changes to Rural Planning Policy: Planning Policy Wales: Edition 3* (Cardiff: Welsh Assembly Government, 2010)

Welsh Assembly Government, *Planning Policy Wales: Technical Advice Note 6: Planning for Sustainable Rural Communities* (Cardiff: Welsh Assembly Government, 2010)

Welsh Assembly Government, *Planning Policy Wales*, 3rd edn (Cardiff: Welsh Assembly Government, 2010)

Wales Rural Observatory, *Rural Classification* (Cardiff: Wales Rural Observatory)

CHAPTER 3.0 HOMEGROWN SITKA SPRUCE IN CONSTRUCTION

Barker 33 Cross-Industry Group, *Modern Methods Of Construction : Executive Summary Of Final Report* (Barker 33 Cross-Industry Group, 2006)

Barker, Kate, *Review of Housing Supply: Delivering Stability – Securing our Future Housing Needs* (Norwich: Her Majesty's Stationary Office, 2004)

Bergdoll, Barry and Peter Christensen, *Home Delivery : Fabricating the Modern Dwelling* (Basel: Birkhauser, 2008)

Berge, Bjorn, *Ecology of Building Materials* (Oxford: Architectural Press, 2000)

BRE, *Digest 445 Advances in timber grading* (Watford: BRE, 2000)

Brown, R.J., *Timber-Framed Buildings of England* (London: Robert Hale, 1986)

Brunskill, R.W., *Timber Building In Britain*, 2nd edn (London: Cassell, 1999)

Brunskill, R.W., *Vernacular Architecture : An Illustrated Handbook*, 4th edn (London: Faber & Faber Ltd, 2000)

British Standards, *BS EN 350-1:1994 Durability of wood and wood-based products*, (London: British Standards Institution, 1994)

British Standards, *BS 5268-2:1996 : Structural use of timber - Part 2 : Code of practice for permissible stress design, materials and workmanship* (London: British Standards Institution, 1996)

British Standards, *BS EN 14081-1:2005 : Timber structures : Strength graded structural timber with rectangular cross section : Part 1: General requirements* (London: British Standards Institution, 2006)

BURA, *Modern Methods of Construction : Evolution or Revolution?* (London: BURA, 2005)

Clifton-Taylor, Alec, *The Pattern of English Building*, (London: Faber & Faber, 1972)

Davies, Colin, *The Prefabricated Home* (London: Reaktion Books, 2005)

Construction Skills, *Construction Skills Network Wales : Labour Market Intelligence 2008 - 2012* (Bridgend: Construction Skills, 2005)

Design Research Unit Wales, *MMC Wales : Achieving Modern Methods of Construction in Wales* (Cardiff: Welsh School of Architecture, 2008)

Dinwoodie, J.M., *Timber: Its Nature and Behaviour*, 2nd edn (London: E & FN Spon, 2000)

Doran, Sean, *Special Digest 7 : Insulation of timber-frame construction* (Watford: BRE, 2008)

Forestry Commission, *National Inventory of Woodland and Trees: Wales* (Edinburgh: Forestry Commission, 2002)

Forestry Commission, *Forestry Facts & Figures 2010* (Edinburgh: Economics & Statistics, 2010)

Forestry Commission, *First Release : Woodland Area, Planting and Restocking* (Edinburgh: National Forest Inventory, 2010)

Forestry Commission, *Forestry Statistics 2010* (Edinburgh: Forestry Commission, 2010)

Forestry Commission, *National Forest Inventory Wales : Distribution of woodland 0.5ha and over* (Edinburgh: National Forest Inventory, 2010)

Forestry Commission, *Timber Price Indices : Data to September 2010* (Edinburgh: Forestry Commission, 2010)

Forestry Commission, *First Release : National Forest Inventory Woodland Area Statistics : Wales* (Edinburgh: National Forest Inventory, 2011)

Forestry Commission, *Forestry Statistics 2011* (Edinburgh: Forestry Commission, 2011)

Forestry Commission, *Tree Species and Provenance : Sitka Spruce* (Edinburgh: Forestry Commission)

Forintek Canada Corp, *Sitka Spruce* (Canada: Forintek Canada Corp)

Hairstans, Robert, *Off-site and Modern Methods of Timber Construction* (High Wycombe: TRADA, 2010)

Hansen, Hans Jurgen, *Architecture in Wood*, (London: Faber & Faber, 1971)

Homes and Communities Agency, *Designed for Manufacture: Lessens Learnt 2* (London: Homes and Communities Agency, 2010)

Jenkins, David, and Haf Roberts, *The Value of Homegrown Timber in the Welsh Economy* (Tregynon: Coed Cymru, 2012)

Johnson, E., *British Grown C16 Timber* (Newbridge: BSW Timber)

Jones, Dennis, *Bridging the Gap Phase 1 : Scoping Study : Welsh timber resources and their potential within the construction industry* (Margam: BRE Wales, 2007)

Klob, Josef, *Systems in Timber Engineering*, (Basel: Birkhauser, 2008)

Linnard, William, *Welsh Woods and Forests : A History* (Ceredigion: Gomer Press, 2000)

Meyhofer, Dirk, *Touch Wood: The Rediscovery of a Building Material*, (Berlin: Verlagshaus Braun, 2008)

MiTEK, *The Posi-Joist Technical Handbook* (Dudley: MiTek Industries)

Mochan, Shaun, and others, *Research Note: Benefits of improved Sitka spruce: volume and quality of timber* (Roslin: Forestry Commission, 2008)

Moore, John, *Wood properties and uses of Sitka spruce in Britain* (Edinburgh: Forestry Commission, 2011)

National Audit Office, *Using modern methods of construction to build homes more quickly and efficiently* (London: National Audit Office, 2005)

NHBC, *A guide to modern methods of construction* (Amersham: NHBC, 2006)

Office of Fair Trading, *Homebuilding market study : Annexe B – New homebuild consumer survey - report on findings* (London: Office of Fair Trading, 2008)

Owen, Julian, *Kit and Modern Timber Frame Homes : The Complete Guide* (Marlborough: The Crowood Press, 2007)

Ozelton, E.C., and J.A. Baird, *Timber Designer’s Manual*, 3rd edn (Oxford: Blackwell Science, 2002)

Pan,Wei, Alistair Gibb & Andrew Dainty, *Offsite modern methods of construction in housebuilding, perspectives and practices of leading UK housebuilders* (Loughborough: BuildOffsite, 2005)

Parliamentary Office of Science and Technology, *Postnote : Modern Methods of House Building* (London: Parliamentary Office of Science and Technology, 2003)

Ross, Keith, *Non-traditional housing in the UK – A brief review* (London: Council of Mortgage Lenders, 2002), p.28.

Sherwood, Roger, *Modern Housing Prototypes* (Cambridge: Harvard Press, 1978)

Smith, Peter, *Houses of the Welsh Countryside : A study in historical geography*, 2nd edn (London: Her Majesty's Stationary Office, 1988)

Steiger, Ludwig, *Basics : Timber Construction* (Basel: Birkhauser, 2007)

Sunley, John, and Barbara Bedding, *Timber in Construction* (London: TRADA, 1985)

Thomson, Michael, *International Markets in Wood Products : Information Note* (Edinburgh: Forestry Commission, 2004)

Timbertrends, *Market Report 2009* (Alloa: UK Timber Frame Association, 2010)

TRADA, *Span tables : for solid timber members in floors, ceilings and roofs for dwellings*, 2nd edn (High Wycombe: TRADA, 2004)

TRADA, *Wood Information Sheet 37 : Softwood Sizes* (High Wycombe: TRADA, 2005)

TRADA, *Timber frame housing: UK Structural recommendations*, 3rd edn (High Wycombe: TRADA, 2006)

TRADA, *Wood Information Sheet 3 : Introduction to timber framed construction* (High Wycombe: TRADA, 2006)

TRADA, *Wood Information Sheet 29 : Trussed rafters* (High Wycombe: TRADA, 2007)

TRADA, *Eurocode 5 span tables : for solid timber members in floors, ceilings and roofs for dwellings*, 3rd edn (High Wycombe: TRADA, 2009)

Twist, Huel, and Robin Lancashire, *Timber Frame Construction*, 4th edn (High Wycombe: TRADA, 2008)

Van Pelt, Robert, *Identifying Mature and Old Forests in Western Washington* (Olympia: Washington State Department of Natural Resources, 2007)

Wilkins, Cedric, *Comparison of home grown and imported softwood for Timber Frame market – Final Report* (Watford: Building Research Establishment, 2004)

Wiliam, Eurwyn, *Traditional Farm Buildings in North - East Wales 1550 - 1900* (Cardiff: National Museum of Wales, 1982)

West, Trudi, *The Timber-frame House in England* (Newton Abbot: David & Charles Ltd, 1971)

INTERNET SOURCES

Forestry Commission, *Sitka spruce - picea sitchensis* (Edinburgh: Forestry Commission) <<http://www.forestry.gov.uk/forestry/INFD-5NLEJ6>> [accessed 18 June 2012]

Health and Safety Executive, *Construction Industry* (London: Health and Safety Executive, 2011) <<http://www.hse.gov.uk/statistics/industry/construction/injuries.htm>> [accessed July 2011]

MORI, *Attitudes Towards House Construction Year 2001* (London: Ipsos MORI, 2001) <<http://www.ipsos-mori.com/researchpublications/researcharchive/1422/Attitudes-Towards-House-Construction-Year-2001.aspx>> [accessed May 2011]

Smit, Josephine, *20 years after World in Action, Barratt goes back into prefab* (London: Building.co.uk, 2003) < <http://www.building.co.uk/news/finance/20-years-after-world-in-action-barratt-goes-back-into-prefab/1030087.article>> [accessed March 2011]

The Construction Index, *Timber-frame most popular social housing building method, despite fire risks* (The Construction Index, 2010), <<http://www.theconstructionindex.co.uk/news/the-construction-index-news/Timber-frame-most-popular-social-housing-building-method-despite-fire-risks>> [accessed 20 October 2011]

Williams, Austin, *Wooden performance: moisture content of timber* (Newcastle Upon Tyne: NBS) <<http://www.thenbs.com/topics/constructionproducts/articles/woodenPerformance.asp>> [accessed 01 July 2011]

CHAPTER 5.0 PERFORMANCE SPECIFICATION FOR AFFORDABLE HOUSING

Anderson, Jane, and Nigel Howard, *The Green Guide to Housing Specification* (Watford: IHS BRE Press, 2000)

Department for Communities and Local Government, *Code for Sustainable Homes: A step-change in sustainable home building practice* (West Yorkshire: Communities and Local Government Publications, 2006)

Department for Communities and Local Government, *Delivering Lifetime Homes, Lifetime Neighbourhoods: A National Strategy for Housing in an Ageing Society* (West Yorkshire: Communities and Local Government Publications, 2008)

European Organisation for Technical Approvals, *ETAG 007 : Guideline For European Technical Approval Of Timber Frame Building Kits* (Brussels: European Organisation for Technical Approvals, 2001)

Gaze, Christopher, and others, *The Code for Sustainable Homes simply explained*, 2nd edn (Watford: IHS BRE Press, 2010)

HM Government, *Building Regulations 2006: Part L1A Conservation of fuel and power in new dwellings* (London: NBS, 2006)

HM Government, *Building Regulations 2010: Part L1A Conservation of fuel and power in new dwellings* (London: NBS, 2010)

Housemark Cymru, *The Welsh Housing Quality Standard: Revised Guidance for Social Landlords on Interpretation and Achievement of the Welsh Housing Quality Standard* (Cardiff: WAG, 2008)

Mayor of London, *London Housing Design Guide: Draft for Consultation 2009* (London: London Development Agency, 2009)

NHBC, *NHBC Standards Extra May 2008* (Milton Keynes: NHBC, 2008)

NHBC, *NHBC Standards 2010: Part 1 General Information* (Milton Keynes: NHBC, 2010)

NHBC, 'Chapter 6.2 External Timber Frame Walls', *NHBC Standards 2010* (Milton Keynes: NHBC, 2010)

NHBC, 'Chapter 2.3 Timber Preservation (Natural Solid Timber)', *NHBC Standards 2010* (Milton Keynes: NHBC, 2010)

Welsh Assembly Government, *Design Quality Requirements: Design Standards and Guidance* (Cardiff: WAG, 2005)

Welsh Assembly Government, *Acceptable Cost Guidance/On Costs For Use With SHG Funded Housing In Wales* (Cardiff: WAG, 2007)

INTERNET SOURCES

BM TRADA, *CE Marking for the CPD* (High Wycombe: TRADA) <<http://www.bmtrada.com/cemark.php#ER>> [accessed 10 Jun 2012]

British Board of Agreement, *Attestation of Conformity* (Watford: BBA) <<http://www.bbacerts.co.uk/ce-marking/attestation-of-conformity.aspx>> [accessed 11th May 2012]

Building 4 Change, *Code for Sustainable Homes pushes 'fabric first' approach* (Watford: BRE Trust, 2010) <<http://www.building4change.com/page.jsp?id=560>> [accessed on 14 May 2012]

Department for Communities and Local Government, *Code for Sustainable Homes and Energy Performance of Buildings: Cumulative and quarterly data up to December 2010* (West Yorkshire: Communities and Local Government Publications, 2011) <<http://www.communities.gov.uk/publications/corporate/statistics/codesustainablesapq42010>> [accessed 14 May 2012]

Dunkley, Daniel, *Zurich To Exit New-Home Warranty and Building Control Markets* (London: Post Online, 2009), <<http://www.postonline.co.uk/post/news/1556918/zurich-exit-home-warranty-building-control-markets>> [accessed 11th May 2012].

EOTA, *What is an ETAG?* (Brussels: EOTA) <<http://www.eota.be/en-GB/content/what-is-an-etag/7/>> [accessed 10 Jun 2012]

EOTA, *What is an ETA?* (Brussels: EOTA) <<http://www.eota.be/en-GB/content/what-is-an-eta/4/>> [accessed 10 Jun 2012]

EOTA, *EOTA Member List* (Brussels: EOTA), <<http://www.eota.be/en-GB/content/eota-member-list/42/33/>> [accessed 11th May 2012]

Greater London Authority, *London Housing Design Guide* (London: Greater London Authority, 2010) <<http://www.london.gov.uk/who-runs-london/mayor/publications/housing/london-housing-design-guide>> [accessed 11 May 2012]

NHBC, *Why choose Buildmark Choice for affordable housing?* (Milton Keynes: NHBC), <<http://www.nhbc.co.uk/Warrantiesandcover/Buildersanddevelopers/Affordablehousing-BuildmarkChoice/>> [accessed 11th May 2012]

NHBC, *Frequently Asked Questions* (Milton Keynes: NHBC), <<http://www.nhbc.co.uk/Builders/Builderregistration/BecomingNHBCregistered/FAQs/>> [accessed 11th May 2012]

Passivhaus, *The Passivhaus Standard : Outline Specification* (Cardiff: Building Research Establishment Ltd, 2011) <<http://www.passivhaus.org.uk/standard.jsp?id=18>> [accessed 14 May 2012]

Welsh Assembly Government, *Policy Statement - Welsh Assembly Government announces target for first changes to Welsh Building Regulations* (Cardiff: Welsh Assembly Government, 2010) <<http://wales.gov.uk/topics/housingandcommunity/housing/publications/buildingregsstatement/?lang=en>> [accessed 14 May 2012]

Welsh Assembly Government, *Written - Towards a Zero Carbon Future for Buildings in Wales* (Cardiff: Welsh Assembly Government, 2008) <<http://wales.gov.uk/about/cabinet/cabinetstatements/2008/zerocarbon/?lang=en>> [accessed 14 May 2012]

Welsh Assembly Government, *Social Housing* (Cardiff: WAG), <<http://wales.gov.uk/topics/housingandcommunity/housing/social/?lang=en>> [accessed 11th May 2012].

CHAPTER 6.0 COMPONENT TESTING + DEVELOPMENT

Burroughs, *Ladder Beam Testing Summary* (Cardiff: Burroughs, 2009)

Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009)

Burroughs, *Ty Unnos Component Toolkit*, 1st Edn (Cardiff: Burroughs, 2009)

Burroughs, *Ty Unnos Component Toolkit*, 2nd edn (Cardiff: Burroughs, 2011)

Coed Cymru, *Panel Tests Mar 09* (Tregynon: Coed Cymru, 2009)

Cowley Timberwork, *Ty Unnos : Prototype Beam Test* (Lincoln: Cowley Timberwork, 2007)

Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007)

Muller, C., *Laminated Timber Construction* (Germany: Birkhauser, 2000)

Utzon, Jorn, *Jorn Utzon Logbook Vol. V : Additive Architecture* (Hellerup: Edition Blondal, 2009)

OTHER SOURCES

Martin, T. (2010, June 22). *2227 - Rotafix Box Beam Connection Testing: Glamorgan Box Beam Testing*, Letter to D.Jenkins.

Martin, T. (thomas.martin@burroughs.co.uk). (2010, October 11). – *2187 - Ty Unnos TSB - Ladder Beam Testing Results*. Email to D.Jenkins (davidj@coedcymru.org.uk).

Martin, T. (thomas.martin@burroughs.co.uk). (2010, November 18). – *2250 - Steel crossbracing feasibility study - comparisons of options*. Email to D.Jenkins (davidj@coedcymru.org.uk).

CHAPTER 7.0 DESIGN PATTERN BOOK

Bergkvist, Pat and others, *Swedish Architecture in Wood : The 2008 Timber Prize* (Stockholm: Arvinius Forlag, 2008)

Broto, Carles, *Contemporary Wood Houses*, (Barcelona: Links Books, 2009)

Burroughs, *Technical Assessment of the Ty Unnos System* (Cardiff: Burroughs, 2009)

Design Research Unit Wales and Coed Cymru, *Ty Unnos Sitka Spruce Housing*, 2nd edn (Cardiff: Design Research Unit Wales, 2007)

Health and Safety Executive, *Manual Handling Assessment Charts* (Suffolk: HSE Books, 2003), p. 1.

HM Government, *Building Regulations 2006: Part B1 Fire Safety : Dwellinghouses* (London: NBS, 2006)

HM Government, *Building Regulations 2004: Part M Access to and use of buildings* (London: NBS,

2004)

Mayor of London, *London Housing Design Guide: Draft for Consultation* (London: London Development Agency, 2009)

National Audit Office, *Using Modern Methods of Construction to Build Homes More Quickly and Efficiently* (London: National Audit Office, 2005)

Slavid, Ruth, *Wood Architecture*, (London: Laurence King Publishing, 2005)

Slavid, Ruth, *Wood Houses*, (London: Laurence King Publishing, 2006)

Welsh Assembly Government, *Welsh Design Quality Requirements : Design Standards And Guidance* (Cardiff: Welsh Assembly Government, 2005)

INTERNET SOURCES

Health and Safety Executive, *Manual Handling: Frequently Asked Questions* (Bootle: Health and Safety Executive) <www.hse.gov.uk/contact/faqs/manualhandling.htm> [accessed 30 May 2012]

Lifetime Homes, 16 Design Criteria (up to 5 July 2010) (London: Lifetime Homes, 2011), <<http://www.lifetimehomes.org.uk/pages/design-criteria.html>> [Accessed 14th May 2012]

CHAPTER 8.0 PROTOTYPICAL STUDIES

The Works: Ebbw Vale, *Future Works Housing - Welsh Passive House Design Competition* (Ebbw Vale: The Works, 2009)

CHAPTER 9.0 RURAL STUDIO, TREGYNON

Burroughs, *Doc 2187- Ty Unnos Ladder Beam Timber Specification* (Cardiff: Burroughs, 2009)

Burroughs, *Ty Unnos Frame Connection Development Report Document* (Cardiff: Burroughs, 2011)

Johnson, E., *British Grown C16 Timber* (Newbridge: BSW Timber)

Mayor of London, *London Housing Design Guide: Draft for Consultation 2009* (London: London Development Agency, 2009)

Peate, Iorwerth C., *The Welsh House*, 3rd Edn (Burnham On Sea: Llanerch Press, 2004)

