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Integra House.

DEVECI, G.

2019

Integra House

Average housing in the UK is less affordable for rural dwellers in comparison with urban living. Fuel poverty is a related challenge, being higher in rural than urban areas. In addition to lower incomes, energy inefficiency of rural dwellings is a driver for fuel poverty. Fuel poverty is recognized in the UK as a form of social inequality and injustice. This study features application-based research that creates a single integrated construction system of the walls, roof and floor of the "Integra House" - a singular operation to create a faster, more cost-effective and thermally efficient envelope. This work is carried out through design optimization, prototyping and performance evaluation.

The design used well-understood truss technology to provide the superstructure and envelope for the entire house. The prototyping included two key elements - novelty and performance testing of: a) Elemental prototypes in workshops at the Construction Scotland Innovation Centre (CSIC), Glasgow, and; b) The complete prototype on-site in rural Fraserburgh, Scotland. The design proved that it can reduce fuel poverty, addressing indoor air quality and making considerable reductions in capital and lifecycle costs. Most importantly, it is a fully repeatable model. The initial post-occupancy evaluation confirms that all except one of the outcomes have been met. The project was funded by the CSIC.

Material in this portfolio is taken from three sources:

1. A research report (pages 3-28):
   - DEVECI, G. 2019. *Integra House research project: REF2021*.

2. Four images extracted from a publication by Architecture and Design Scotland (pages 29-30):
   - ARCHITECTURE AND DESIGN SCOTLAND. 2021. *Using offsite construction for housing delivery in Scotland*. Edinburgh: Architecture and Design Scotland [online], cover and page 15. Available from: https://www.ads.org.uk/case-study-using-offsite-construction-for-housing-delivery-in-scotland/

3. A standalone photograph (page 31):
   - BIRDSALL, J. 2021. *Entrance view, the Integra House*. [Photograph]. Taken on 15 May 2021.

In addition, another source is available but not included in this portfolio:

- DEVECI, G. 2019. *This is Integra House*. [Video recording]. Aberdeen: Robert Gordon University [online]. Available from: https://youtu.be/stRPCGTybh0 and https://rgu-repository.worktribe.com/output/910986

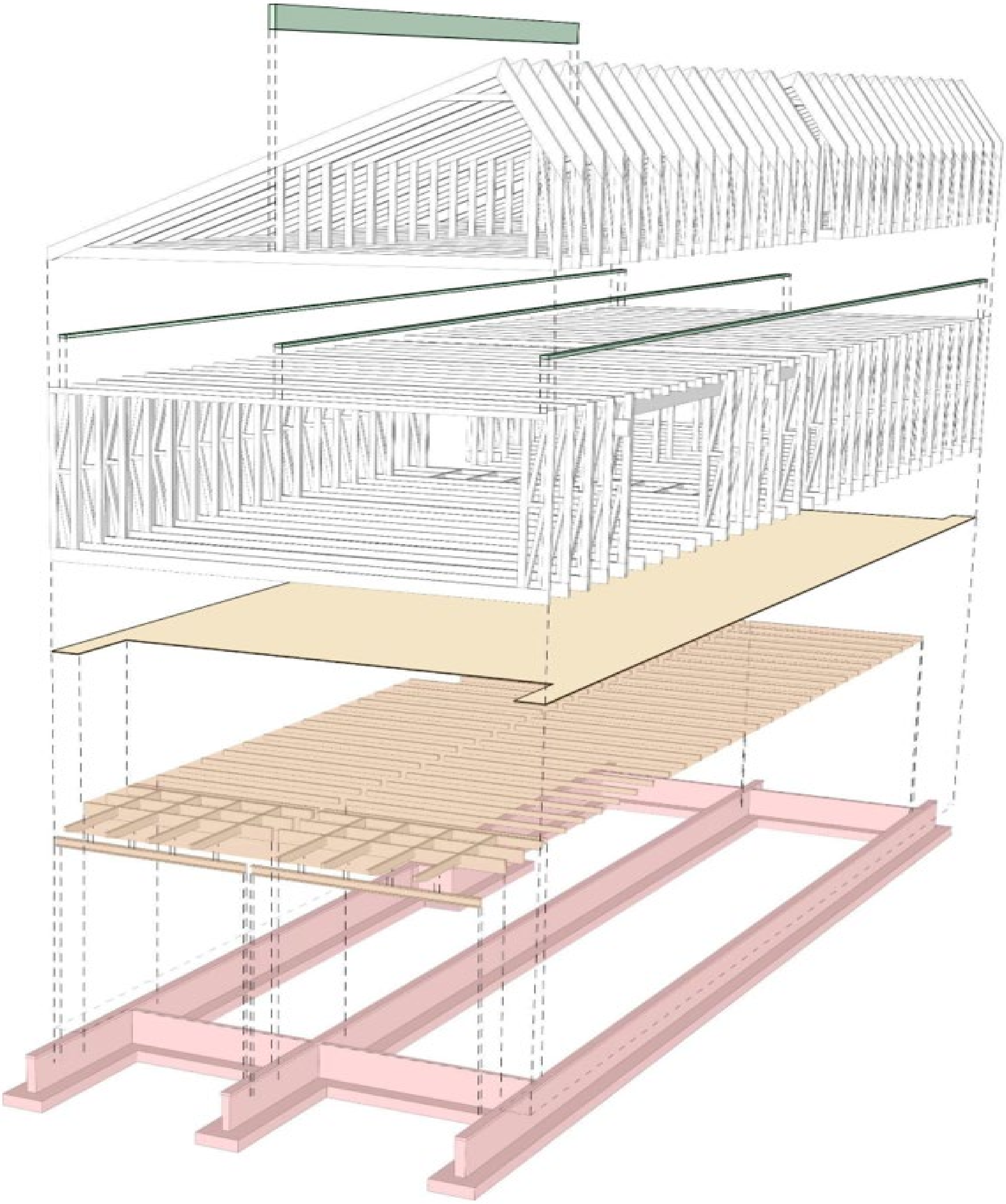
CONSTRUCTION SCOTLAND INNOVATION CENTRE

Sylvan Stuart

PASQUILL SAINT-GOBAIN

RGU

INTEGRA HOUSE



Project Details

Designer	Professor Gokay Deveci RIBA FRIAS - RGU
Title	The Integra House
Output type	Practice-based Research- Design and Building Prototype
Function	Low-energy affordable housing
Location	Rural, Scotland
Client	Private
Completion	November 2019
Budget	£850 per m^2
Area	120 m^2
Industrial partners	Sylvan Stuart Ltd, Pasquill Ltd, STEICO UK Ltd, RGU, and CSIC.

Executive Summary

The average housing in the UK is less affordable for rural dwellers, in comparison with urban living. Fuel poverty is a related challenge, being higher in rural than urban areas. In addition to lower incomes, energy inefficiency of rural dwellings is a driver for fuel poverty. Fuel poverty is recognized in the UK as a form of social inequality and injustice. This study is an application-based research that creates a single integrated construction system of the walls, roof, and floor 'integra house' - a singular operation to create a faster, more cost-effective, and thermally efficient envelope.

This work is carried out through design optimization, prototyping, and performance evaluation. The design used well-understood truss technology, to provide the superstructure and envelope for the entire house. The prototyping included two key elements: novelty and performance testing of: i) Elemental prototypes in workshops at the Construction Scotland Innovation Centre, Glasgow (Fig. 3) and; ii) The complete prototype at site in rural Fraserburgh, Scotland. Truss options and various thicknesses of a blown wood wool insulation solution were tested at the workshops.

The design proved that it's capable of reducing fuel poverty, addressing indoor air quality and making considerable reductions in capital and life cycle costs. Most importantly, it is a fully repeatable model. The initial post-occupancy evaluation confirms, all bar one, of the outcomes have been met. The exception being the heat-transfer idea using the wood burning stove, where data is still being collected. New insights and knowledge gained over a longer evaluation period will be applied to future affordable housing. The next iteration will fine-tune an affordable and user-friendly space heat-transfer innovation, through current plans to replicate at different sites in Scotland and beyond.

Statement about the Research Content and Process

Description

The limitations of timber frame construction and the fuel poverty in rural Scotland has led to the need of finding a more efficient housing solution.
Faced with the challenge, the academia received funding from Construction Scotland Innovation Centre (CSIC) in order to develop an alternative to the existing timber frame housing solutions. Proposing an affordable, energy efficient and competitive product, the project introduces the concept of Integra House.
Integra House is based on a new timber truss type that provides superstructure and the envelope for the entire house: floors, walls and roof. The aim is to introduce a reduction of operations on site and the time spent erecting the structure while simplifying the processes involved. Also, the project targets the ease of buildability in remote rural locations using locally available materials and workforce.

Research Questions

1. What are the advantages and disadvantages brought in by an integrated structural system?

2. How is the buildability of the overall construction process being improved?

3. What strategies can be employed to build towards Passive House standards?

4. What is the economic impact at the level of local employment?

5. What types of clients can benefit from building an Integra House?

Introduction

The average housing in the UK is less affordable for rural dwellers, in comparison with urban living. As of 2016, rural England's lowest-priced homes cost 8.3 times of local incomes, compared with 7 times in urban areas [1]. Fuel poverty is a related challenge, being higher in rural than urban areas [2]. In addition to lower incomes, energy inefficiency of rural dwellings is a driver for fuel poverty. Fuel poverty is recognized in the UK as a form of social inequality and injustice [3]. Unaffordability of rural housing remains challenging for other countries, with 45% of the world's population living rurally. Yet the majority of current research and innovation in housing quality is focused on urban housing. Addressing these challenges, the aim of the current research was to apply innovative design and construction methods, to create new affordable low-energy housing. Innovation comprised of three strands: Social, Cultural and Environmental. The objectives were to: (i) Design and evaluate options of fabric elemental prototypes, and complete dwelling prototypes; (ii) Build and evaluate the performance of elemental prototypes; (iii) Build and evaluate the performance of a full-scale dwelling prototype; and (iv) Compare capital & life cycle (LC) costs and environmental impacts of the prototype with existing models to affordable low-energy housing.

Historic systems to low-cost housing have included timber frame kits, Structural Insulated Paneled fabrics, and other traditional and hybrid systems. A common shortcoming apparent in these systems is the assembly of floors, walls and roofs as separate elements, in multiple site operations, which increase both time and construction costs. The current research on the 'Integra' house prototype questions the current model and offers optimization. The design innovation delivers a rethinking of the truss, and how to join prefabricated structural truss elements. This creates a single integrated construction system of the walls, roof, and floor - a singular operation to create a faster, more cost-effective, and thermally efficient envelope.

Methods

The methodology involved design optimization, prototyping, and performance evaluation. The design used well-understood truss technology, to provide the superstructure and envelope for the entire house. Roof trusses are the most common and cost-effective way to build roofs in the UK. The design optimization focused on: i) A truss module system to facilitate the assembly of the floor, wall and roof as continuous elements; ii) Simplifying construction by reduction of operations, construction time, and waste; and iii) Addressing housing fuel poverty, well-being in rural locations, and utilizing local workforce and self-build opportunities where possible. The optimization involved: i) CAD iterations of options of floor plans, sections, truss types, and dwelling forms between the architect, structural engineer, and quantity surveyor; and ii) Analysis of capital and LC costs of test options, and comparison with existing solutions. The engineer analyzed the truss types based on spacing, room widths, requirement of load bearing walls, and girders vs. widths of openings.

The prototyping included two key elements: novelty and performance testing [5] of: i) Elemental prototypes in workshops at the Construction Scotland Innovation Centre, Glasgow (Fig. 3) and; ii) The complete prototype at site in rural Fraserburgh, Scotland (Fig. 8 & 9). Truss options and various thicknesses of a blown wood wool insulation solution were tested at the workshops. This articulated the cost-effective optimum, meeting requirements for structural strength, breathable wall construction, and low-energy standards. The insulation trials were incorporated in one of the design options, and tested separately on the ground floor walls, and then on first floor walls together with the roof system. Air leakage tests, thermal imaging, and experiments on a concept of heat distribution from a wood burning stove in the lounge to the bedrooms (Fig. 10) formed part of site-based prototyping. Post occupancy monitoring of Carbon Dioxide, Particulate Matter (PM2.5) Temperature and Relative Humidity is ongoing.

Dissemination

The conclusions of the project are meant to inform several target groups: the academia, industry, government and the clients. Therefore, an important part of the project lies in the dissemination process that will take place after the actual completion of the research (June 2018).

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Design and Construction of the Integra House

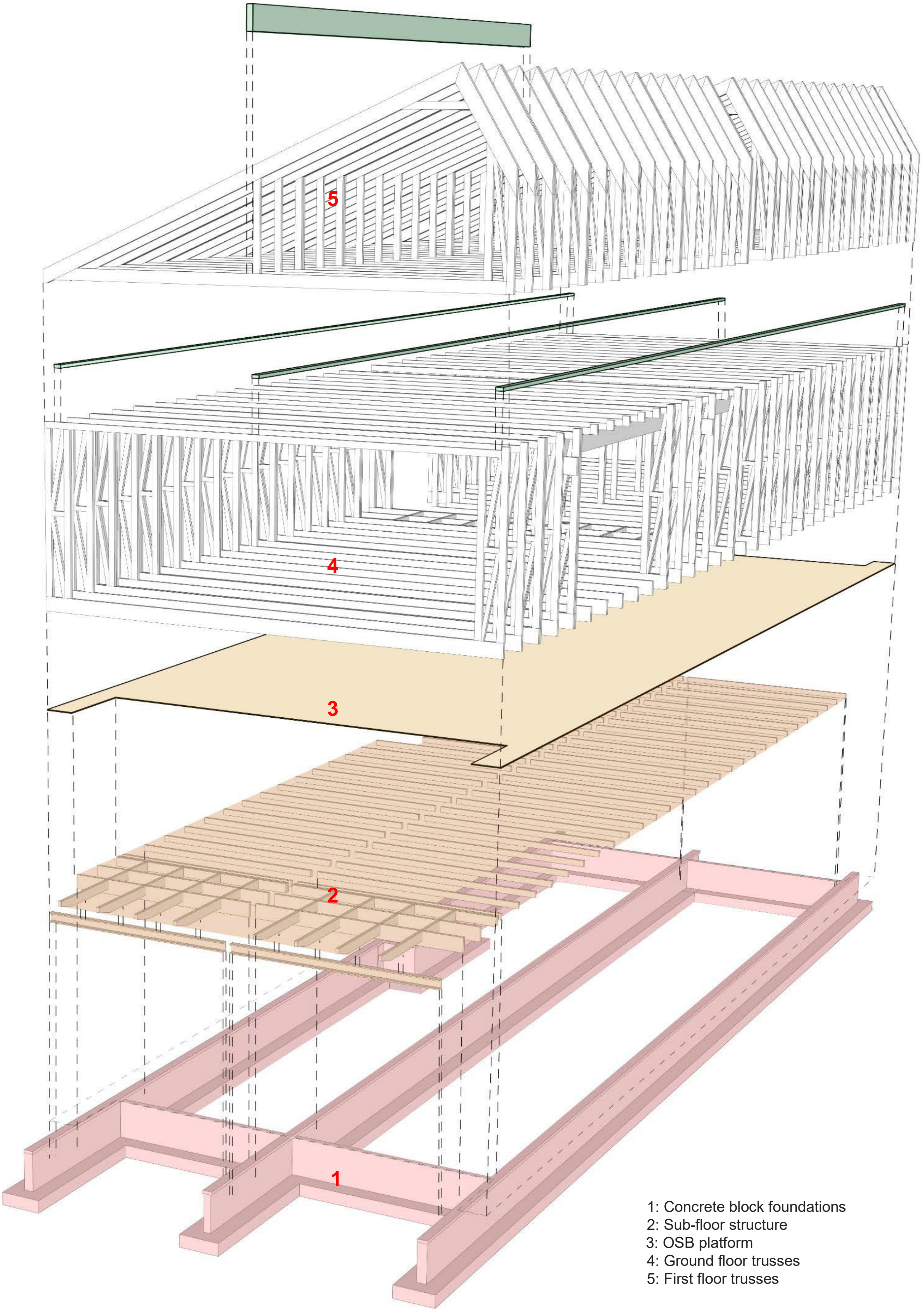


Fig. 1. Main Building components' Stratification

Anatomy of trusses and the development process

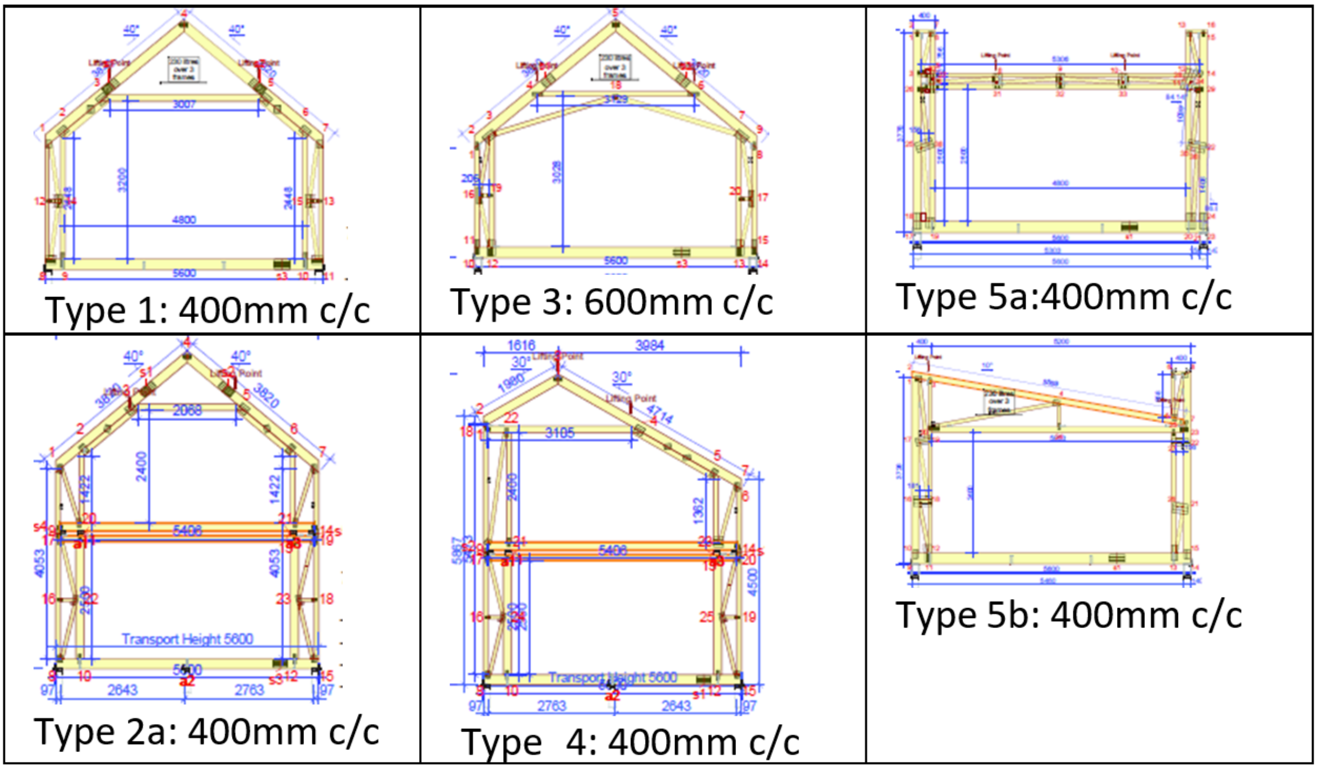


Fig. 2. Six trusses used (assessed via structural analysis)

Fig. 3. Workshop tests of trusses & wood blown insulation at Hamilton, CSIC.

Fig. 4. Individual truss frames being put in place with light-weight machinery

Fig. 5. Two men are enough to assemble the whole house

Fig. 6. Ground floor and first floor trusses put in place

Fig. 7. The water-tight Integra House typology

Fig. 8. The completed Integra House typology

Fig. 9. The Integra House and the landscape

Fig. 10. Sample of performance monitoring sensor positions

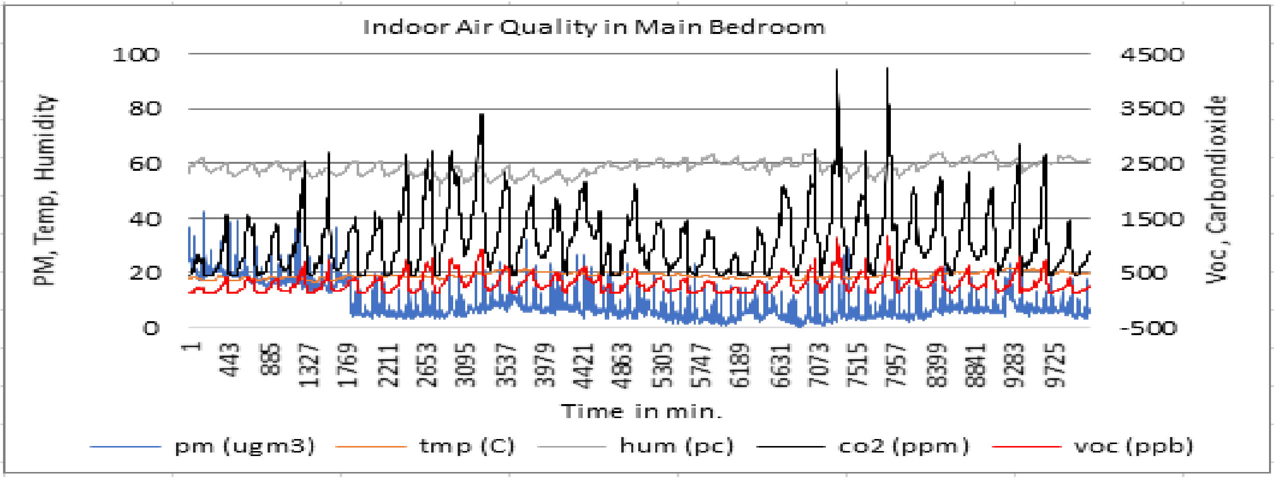


Fig. 11. Monitored internal air conditions – 3.5.19 to 9.7.19

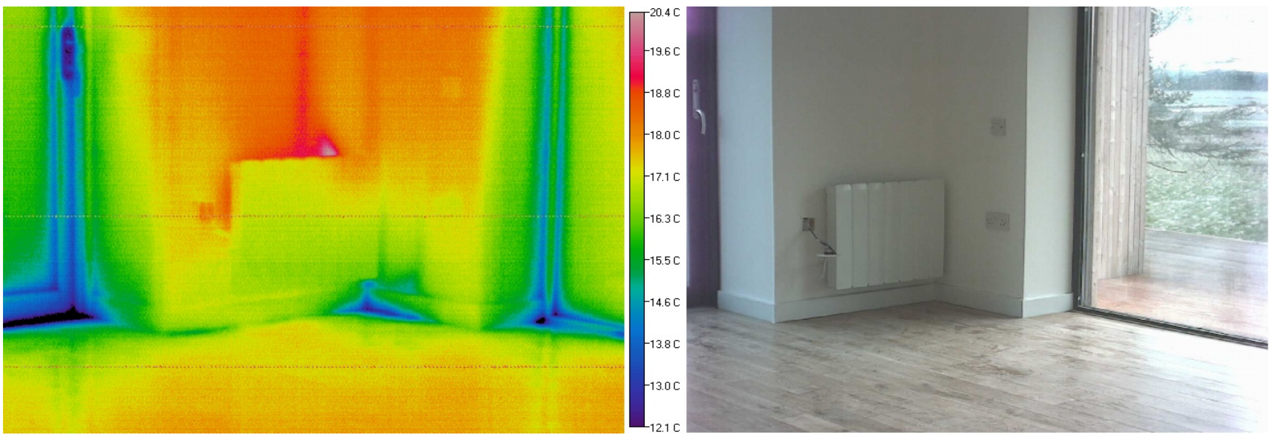


Fig. 12. Sample thermal images in mid-winter – 09.01.19

Aims and Objectives

The knowledge base accumulated in this research project aims to realize the identified building typologies and build them in the context of rural Scotland.

Cost Objectives

By implementing the Integra House typologies, the process aims to safeguard jobs in the rural area by involving small construction companies in the supply chain. Also, the capital investment (through the scalable character of the house) will contribute to the growth of the small companies involved in the erection of Integra House types.

Also, in order to attain a cost certainty for the client, there will be proposed a limited range of house typologies that can be customized using a catalogue of components, materials and appliances.

Design Objectives

The research looks at taking full advantage of the "laser technology engineered timber" by providing both the structure and the envelope as an alternative to the panelized methods.

Also, the research looks into minimizing the additional support of services during the building's erection while reducing the number of contractors on site.

Another important objective is identified in the designing to meet Passive House standards that will provide superior energy performance and comfort. This aspect is part of the aim to address the fuel poverty in rural area.

Social Objectives

Underlining the whole process, there are several indirect objectives that aim the client, the builder and the architect.

By choosing an Integra house, the client will be encouraged to responsibly inhabit the space by directly deciding on the specifications of the building and by responsibly making decisions about the energy consumption.

The builder will benefit from employment opportunities in the small communities.

Eventually, throughout the process, the architect has the possibility to gain a better understanding of the client's needs and apply the conclusions to improve the Integra House typologies.

Questions

1. What are the advantages and disadvantages brought in by an integrated structural system?
First of all, the use of a truss system over timber frame construction would bring, by the nature of the wall construction a minimum 400mm deep space to fill with insulation. The speed of erection will reduce or limit the number of contractors on site in the same time, simplifying the application of CDM regulations. The optimization of the erection process will provide a waterproof shell (the truss structure with external cladding) that can allow the fitting of insulation, services and finishes independent from the weather.

2. How is the buildability of the overall construction process being improved?
In terms of improving the overall buildability there are certain aspects that are addressed through the Integra House project: the standardization of components and processes by benefiting from the prefabrication processes. In this way, the potential risks involved during the works on site will be limited and lowered. The reduction in complexity of the construction process will help avoiding long and complicated learning curves. Considerable time will be saved allowing for the works on site to progress at a fast pace.
Also, the flexibility of plan organization will be enhanced by developing a scalable house type (system) with no investment in expensive manufacturing equipment. The main advantage of the truss is that it evenly distributes the loads. Therefore, the proposed plans for the Integra House have to make the best use of this principle.
Therefore, there are proposed linear plan types. In a linear truss building, the openings at the gable ends are not dependent on a lintel. On the long elevations, there could be introduced openings spanning between two consecutive trusses or across several trusses by introducing a lintel.
This aspect contributes towards keeping the structural integrity of the trusses and towards maintaining the affordability of the project.
Still, there appear limitations to planning imposed by the position and orientation of the internal staircase, i.e. the stair needs to run parallel to the trusses in order to avoid damaging the structural integrity (i.e. cutting too many trusses).

3. What strategies can be employed to build towards Passive House standards?

As Integra House is aiming to reach Passive House standards, the energy performance levels need to be in accordance to the strict thermal performance requirements of Passive House design.

Mainly, there are being analyzed five aspects:

<u>Airtightness</u>
There has been proposed an airtight vapour permeable membrane on the outer face of the external walls. Supported on 11mm OSB sheeting, the membrane creates a weathertight envelop. In order to benefit from the high levels of airtightness the building needs to have a controlled ventilation system and the critical junction points need to be solved accurately.

Insulation

Due to the nature of the construction (the truss technology), the minimum depth of the external walls is 400mm. This inherent aspect of the construction allows for the necessary levels of insulations in order to meet the target U-Values.

Passive solar design

The compact design of the linear truss houses ensures the heat loss is minimal. Also, the large glazed gable ends are orientated towards the sun, maximizing the solar gain during the cold season.

Heating

There has been introduced a wood burning stove that will provide the heating for the entire house. A secondary electrical heating system can be used as a back-up if the client wishes to do so.

Windows

All windows and external doors are manufactured to a high standard of insulation. There have been proposed triple glazing windows with super low E and/or Argon Gas reaching a U- Value of 1W/m2k.

4. What is the economic impact at the level of local employment?

Furthermore, the economic impact at the local level in rural areas will involve offering employment by identifying the local work force, contractors and suppliers and encouraging self-build construction. Also, the fuel poverty in rural areas will be addressed by building to Passive House standards aiming to provide superior energy comfort and performance.

5. What types of clients can benefit from building an Integra House?

This research relates to different groups that could take advantage and benefit from the underlying principles of the Integra House:

- timber supply companies interested in the fully integrated truss design
- private clients that are looking for an affordable solution for their house
- mass volume house builders

Fig. 13. The depth of the truss wall filled with mineral insulation

Note: minimizing the cold bridges

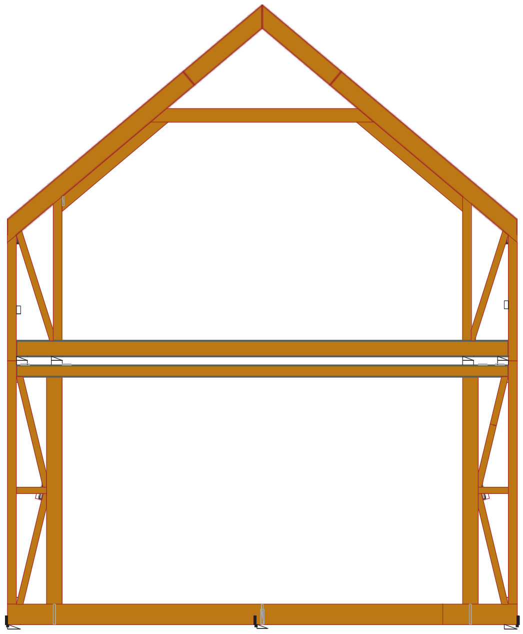


Fig. 14. Laser technology engineered timber

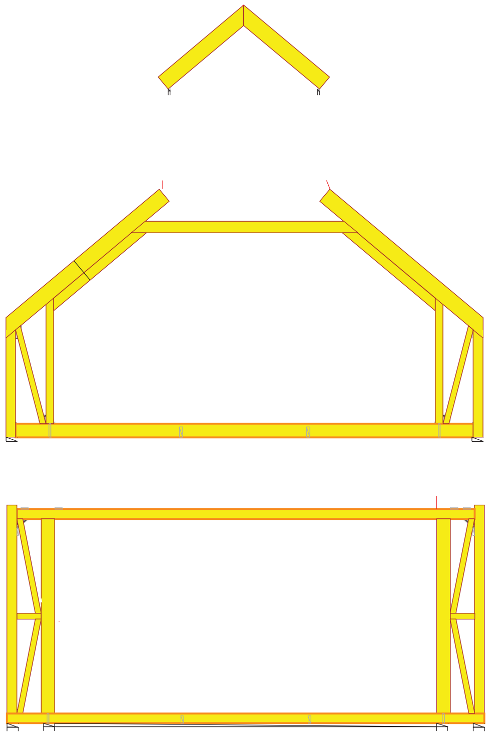


Fig. 15. Precision and coordination during the assembly process.

Context

The development of the Integra house research project has been characterized by a continuous learning curve that relied heavily on the outcomes generated by the building prototype in Tyrie, Scotland.
Besides this, the continuous collaboration and dialogue with the other stakeholders provided the project with a wealth of practical information.

Development of a new wood-based product

As a result of one of the team meetings, Sylvan Stuart Ltd, the contractor and the client of the pilot house built in Tyrie applied for the Advanced Timber Products Innovation Challenge released by CSIC. This decision appeared as a reaction to the need to test the blown wood fibre insulation into the Integra House wall.

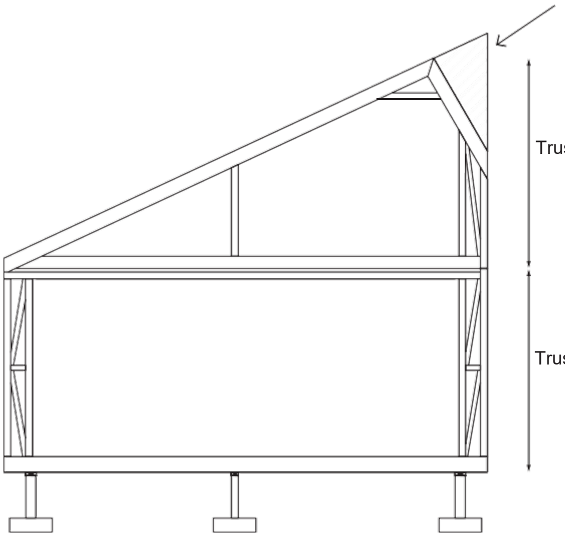
Life-cycle cost assessment

An important part of the research project lies with the assessment of the life-cycle cost that involves the environmental impacts associated with all the stages of the building's life.

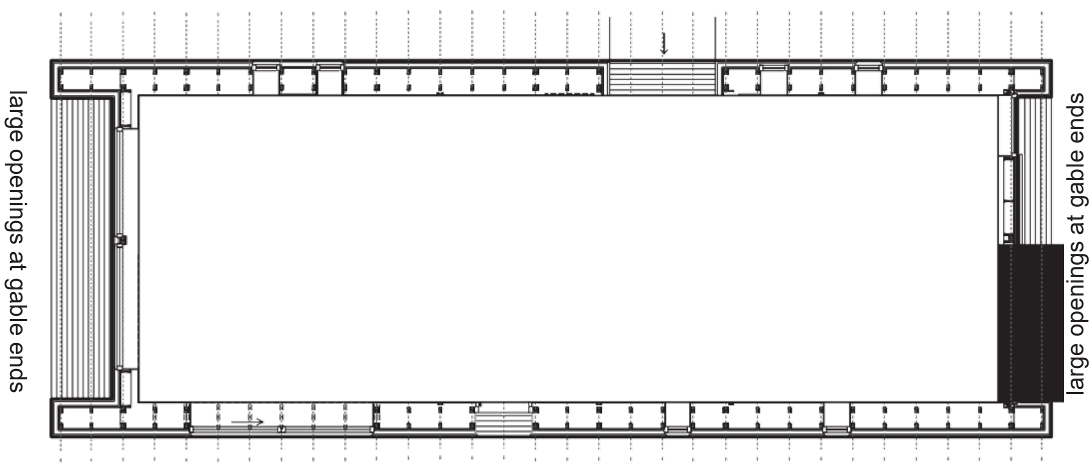
Environmental assessment

The completed pilot house in Tyrie will allow the team to perform the airtightness test. The conclusions from this test will highlight the weak points at the junctions, allowing for improvements in the proposed typologies.

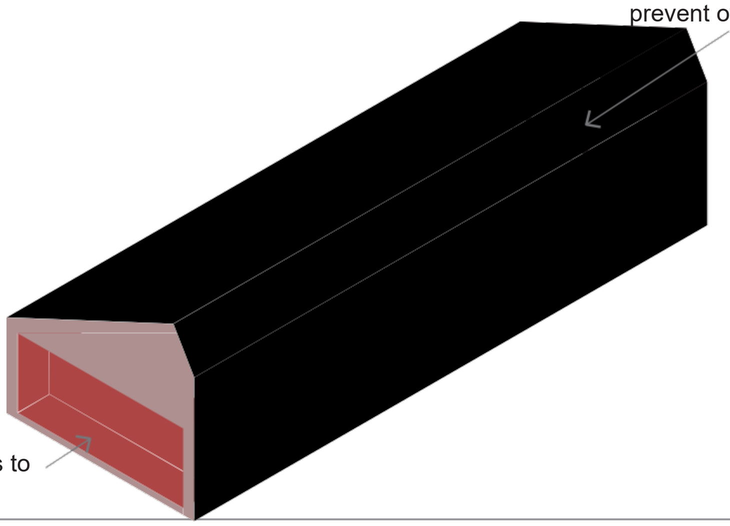
Principle 1
Identifying the most efficient section

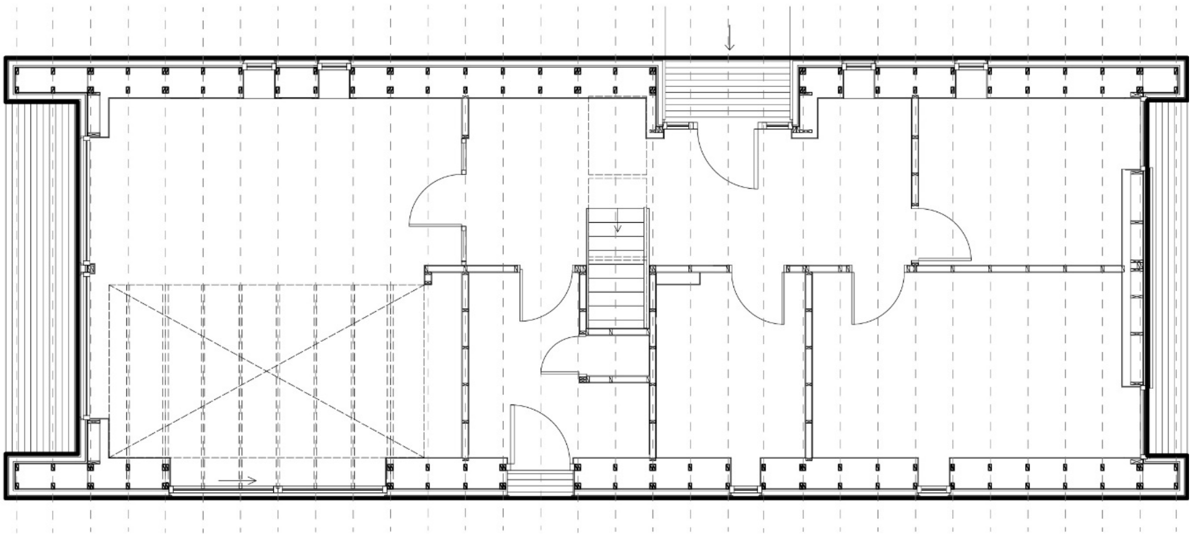


Principle 2
Traditional Scottish long house

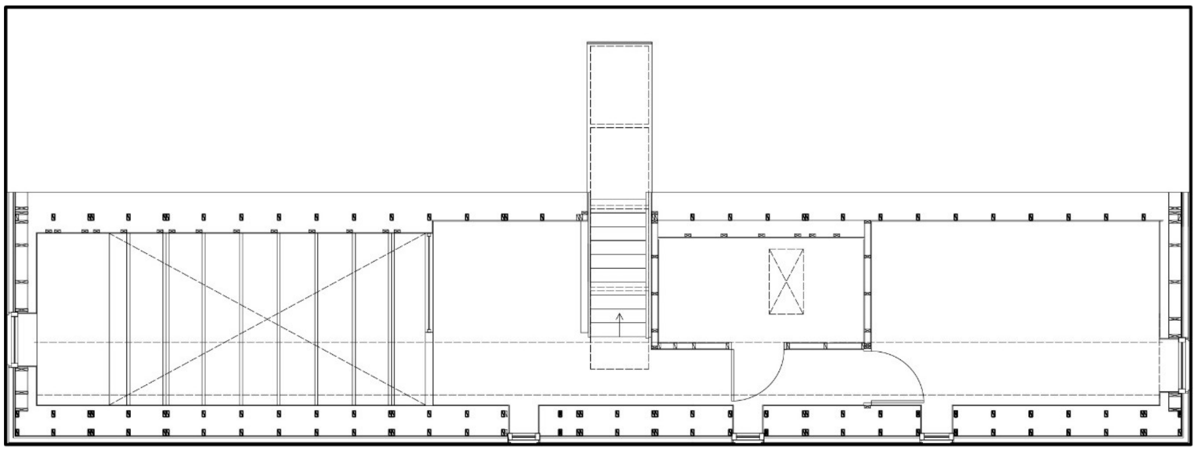


Principle 3
Energy efficiency

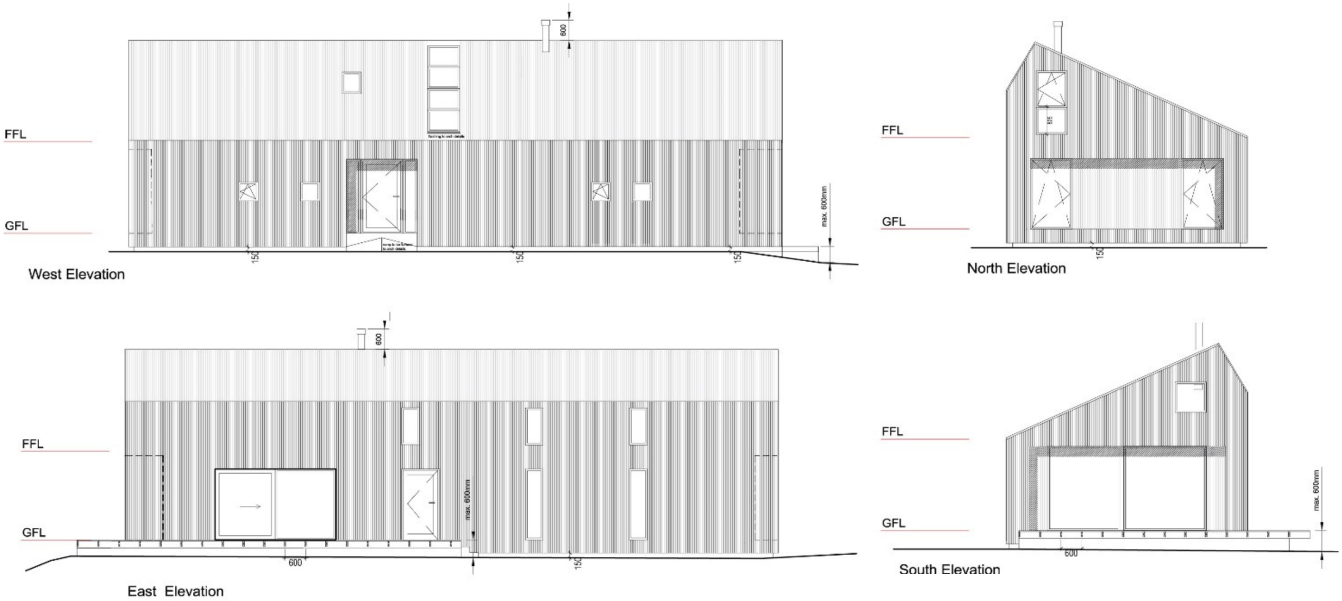




Ground Floor



First Floor



Elevations

Methods

Choosing the typologies

From the outset, the main outcome of the research project was the identification of Integra House Typologies that would meet the client's needs.

Based on this, the lessons learned from the pilot house built in Tyrie, together with the desk research that investigated the technical and structural limitations of the truss, the logistics and assembly of the truss system off-site and on-site lead to the definition of two Integra House typologies.

Type 1, based on a scissors roof truss defines a one storey typology.

Type 2a, based on a composed truss, defines a one and a half storey typology.

Working with the limitation of the truss system

In order to achieve these two typologies, the team went through an iterative process of understanding the limitations brought by an integrated truss system. The constant exchange of information with the truss manufacturer informed the choices about the sizes of the truss, the internal organization of the plan and the position and sizes of openings.

It is worth mentioning several factors that influenced the final design decisions:

- The height of the truss manufacturing machine: 4.1m
- The depth of the wall of the truss is highly dependent on the wind load, the type of the structural system (number of pin joints or roller joints), the number of storey and the distance between the centres of the trusses. The depth of the wall (min. 400mm to 600mm) is directly linked to the amount of insulation.
- Trying to avoid having two openings on the long elevations that line up with each other, as this will prevent cutting both wall elements of the same truss.
- In order to prevent the damage on the structural integrity of the truss system, the internal staircase should run parallel to the trusses.

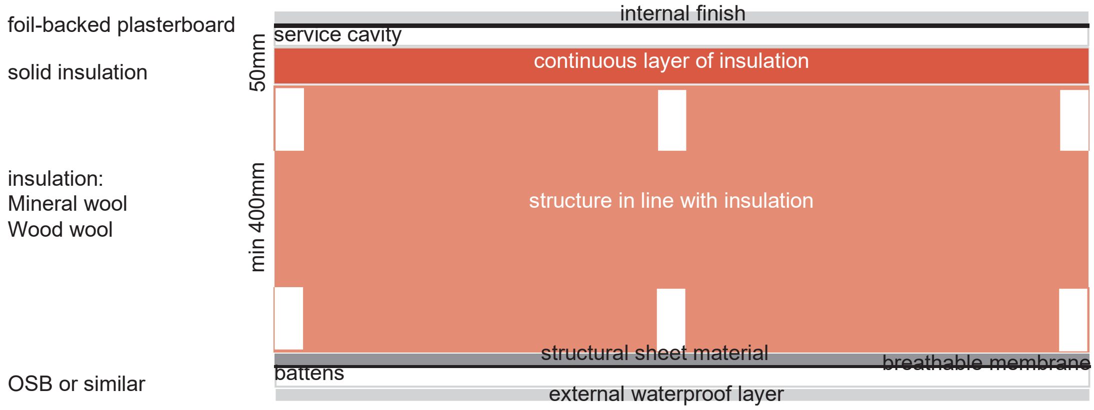
The character of the plans associated

As already mentioned, the timber truss structural system influences the internal layout of the Integra House typologies. Collaborating with the client (Sylvan Stuart Ltd), we settled upon a series of plans for both the single storey typology and the 1.5 storey typology that would suit several requirements.

Working with variables like the position of the entrance, of the living/dining space, the number of bedroom and the total area of the house, we identified several plan typologies associated with the two main Integra House types.

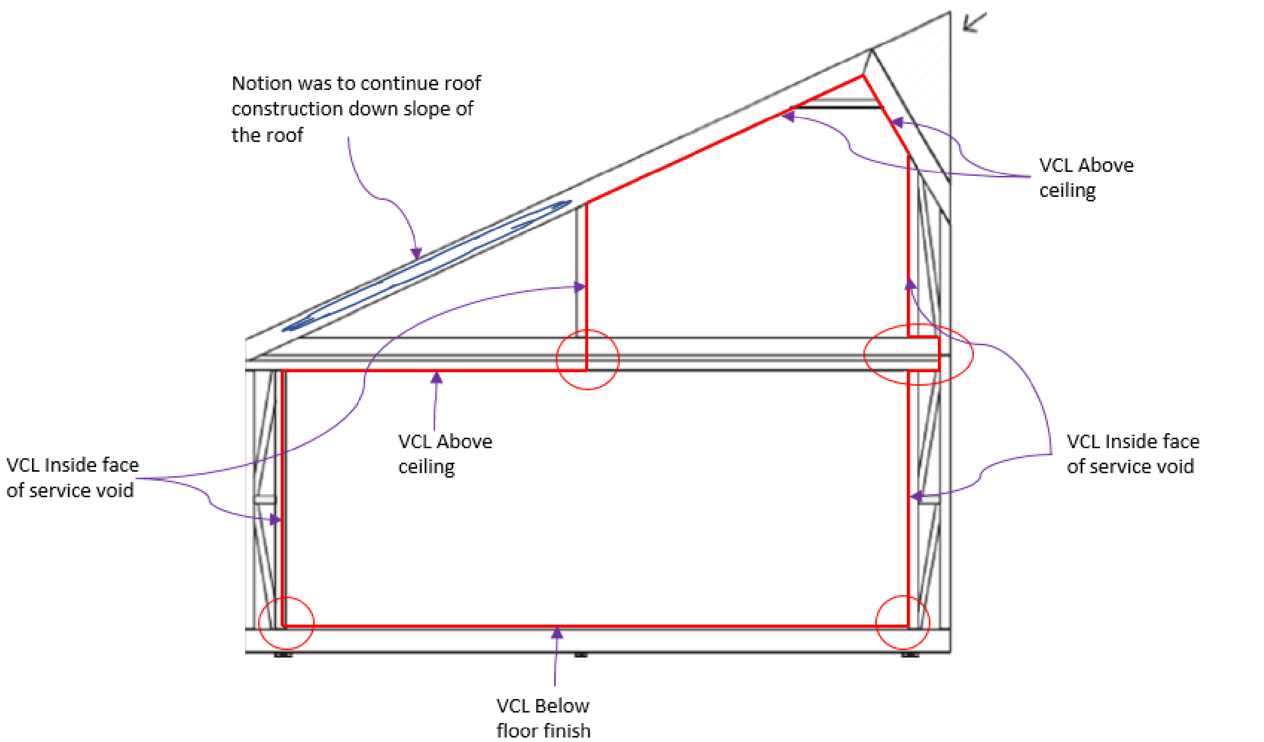
Dividing the work in four Work stages

Overall, the research work has been divided into four stages: concept design for the Integra House typologies, the technical and structural design, the logistics, assembly and testing and the cost analysis.



Mineral wool		Wood wool
400mm	600mm	600mm
U-Value= 0.12	U-Value= 0.09	U-Value= 0.08

Energy performance of the wall Integra House wall

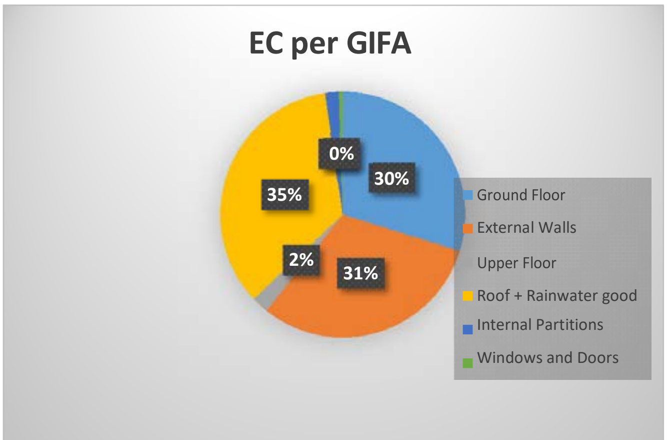


AIR TIGHTNESS STRATEGY

Embodied Carbon per Gross Internal Floor Area

	EC per GIFA
Ground Floor	167.18
External Walls	173.39
Upper Floor	12.80
Roof + Rainwater good	194.74
Internal Partitions	10.04
Windows and Doors	3.00
	561.15

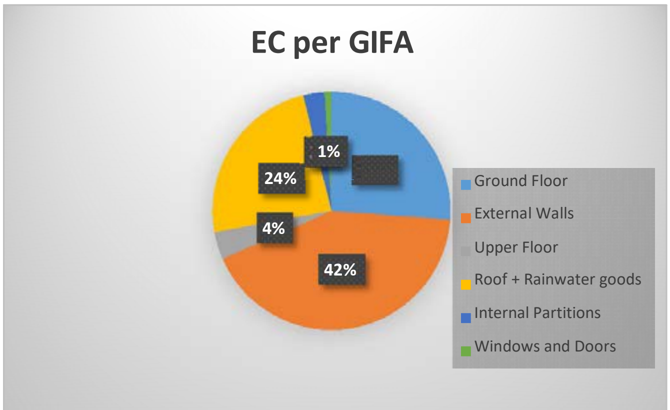
Excluding foundations, fittings and services



(1) Mineral wool insulation

	EC per GIFA
Ground Floor	83.23
External Walls	134.35
Upper Floor	11.88
Roof + Rainwater goods	76.47
Internal Partitions	9.17
Windows and Doors	3.00
	318.10

Excluding foundations, fittings and services



(2) Wood-fibre insulation

Life cycle cost assessment

Compilation of the information in a report, presentation and an article

The conclusions of the project are meant to inform several target groups: the academia, the industry and the private clients. Therefore, an important part of the project lies in the dissemination process that will take place after the actual completion of the research (June 2018).

During the research, all the information has been compiled in a report that highlights the iterative and collaborative process that the project relied on.

On completion there will be released an executive summary report, a presentation and an article.

What next?

The most important target of the research project concerns the application of the Integra House concept widely across Scotland. While the guidelines have been laid throughout this research, the practical implementation of the product will require further steps and collaboration with the industry.

Dissemination

The conclusions of the project are meant to inform several target groups: the academia, the industry and the private clients. Therefore, an important part of the project lies in the dissemination process that will take place after the actual completion of the research (June 2018).

The prototype house is a practice-based research project, improving the provision of energy efficient, resilient, healthy and genuinely affordable housing. The design proved that it's capable of reducing fuel poverty, addressing indoor air quality and making considerable reductions in capital and life cycle costs. Most importantly, it is a fully repeatable model. The initial post-occupancy evaluation confirms, all bar one, of the outcomes have been met. The exception being the heat-transfer idea using the wood burning stove, where data is still being collected. New insights and knowledge gained over a longer evaluation period will be applied to future affordable housing. The next iteration will fine-tune an affordable and user-friendly space heat-transfer innovation, through current plans to replicate at different sites in Scotland and beyond.

Also, the project received became gradually more visible in the local area due to the research collaborators as Pasquill Ltd that are willing to provide logistical support for the fulfilment of the project.

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Architecture & Design Scotland
Ailtearachd is Dealbhadh na h-Alba

Using Offsite Construction for Housing Delivery in Scotland

Top and right: Integra House,
Aberdeenshire,
Images by Gokay Deveci