From barn to haus:

understanding the potential of alternative approaches to deliver more | better homes

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a. Year of output: 2013 - 2018

b. Type of output

vii. Discussion of the process by which a single design concept led to two distinct domestic construction methods, developed and tested through a constructed prototype and two completed projects, as a means of discussing the relevance of alternative approaches to housing delivery.

c. Title of the output:

From barn to haus: understanding the potential of alternative approaches to deliver more | better homes

d. Funders/Clients

NASBA (National Self Build Association) with Grand Designs (design competition)
V2C (Valleys to Coast) Housing Association (client, project 1)
IHP (Innovative Housing Programme) via Welsh Government (funder, project 1)
Glastonbury festival (client, prototype - project 2)
private domestic client (client, project 2)

1. Each of the following is required where applicable to the output:

a. Co-authors: none

b. Interdisciplinary research:

The panel should note that this research is the product of collaborative working. It involved a number of industry collaborators, including:

Pentan Architects
Cambria structural engineers
Momentum Engineering
RPA cost consultants
V2C (Valleys to Coast) Housing Association
Design Commission for Wales
FMB (Federation of Master Builders)
Energy Savings Trust
CIOB / CITB
CCHC
NaCSBA (National Custom and Self Build Association)
Grand Designs / Media10

c. The research group:

Research Practice group, Welsh School of Architecture, Cardiff University

Summary statement

"For any submitted output where the research content and/or process is not evident from the output itself, such as non-text outputs, submissions should include a statement of up to 300 words which identifies the research questions, methodology and means of dissemination". REF guidance 2014

Research questions

The primary aim of this research is to explore and understand the importance of alternative approaches to housing delivery, in the context of the ongoing UK housing crisis.

The collected narrative explains the development of an approach for delivering houses in rural locations that are more suited to their contexts than the 'bricks and mortar' approach typically adopted by small scale housebuilders.

By employing forms, materials and techniques more commonly used in rural contexts, the intention is to achieve higher quality in both design and performance, improve flexibility in use, and maximise affordability and replicability.

The narrative compares two such approaches – one developed for a main contractor and the other intended for true self-build construction. The work is in the context of a clear need for housing more suited to rural locations, and the potential environmental, ecological and health benefits of better performing, lower carbon dwellings.

Methodology

Research was conducted through development of a design concept into two fully developed construction methods, both of which are tested on site (currently under construction), and necessitated the following stages:

• Concept produced for international design competition.
• Developed as a contractor-led construction package.
• Developed as a self-build construction package.
• Constructed as a contractor-led social housing project (V2C HA, Bridgend).
• Constructed self-build project (prototype, Glastonbury festival then private home, Torfaen).

Means of dissemination

Dissemination has taken place through:
• winning an international design competition (September 2013).
• dissemination via a wide range of media, including BBC news, Grand Designs Live (NEC, Birmingham 2013), Shelter Cymru AGM (July 2014) and numerous subsequent industry and academic publications.
• evidence provided for Welsh Government's Housing enquiry (2017).
• demonstration - physical projects, one of which went to Glastonbury festival.
• social media – reporting of on-site progress built a network of more than 1500 followers (2017-2018).
• inclusion in Welsh Government's Innovative Housing Programme – monitoring, evaluation and reporting (ongoing, 2018-2020).

[words 299]

Contents

1. Abstract

"To ensure that practice-based outputs are assessed on an equal basis with other outputs, submissions should include an explanatory presentation of the building or design in an easily-handled paper-based format, to allow the panel to understand the output without visiting it, and to make a judgement of its research contribution."

This paper presents a series of interconnected pieces of research within a single narrative that connects each piece of work back to a focussed research agenda.

The research agenda described by this paper is directed at developing an understanding of ways in which alternative approaches to housing delivery could increase our capacity to build *more* homes, and improve opportunities for making *better* homes when their impact is considered holistically. The research includes:

- A design concept based on a perceived need for high quality, affordable, context-appropriate housing for rural locations (submitted for an international competition).
- Development of the concept into a detailed design proposal suited to contractor-led projects (ie. a professional constructor project managing the project) – approach A.
- Development of the concept into a detailed design proposal suited to true self-build (ie. Constructed by the occupier, who is not a professional constructor) – approach B.
- Construction of a 4-dwelling housing scheme, delivered by a main contractor (including a comparison of two constructional variations – project A, ongoing).
- Construction of a prototype (for project B).
- Construction of a single dwelling by a true self-builder (project B).

Section 2 of this paper introduces the context to the research, identifying three factors that were central to the development of the research: the UK-wide incentives for greater production of homes from the self- and custom-build sectors, the long term drive for greater update of MMC (modern methods of construction) and their perceived benefits, and the need for alternative housing models more suited to rural and edge-of-settlement locations.

Section 3 explains the development of the *Barnhaus* concept, an approach for delivering homes in rural locations that sets out to produce high quality, affordable houses by utilising materials and techniques more familiar in rural contexts, in order to produce dwellings more suited to such locations. Section 3 also describes how the concept won an international design competition and was subsequently disseminated internationally.

Section 4 describes the thinking behind the development of two parallel constructional approaches – one based around MMC and focussed on contractor-led delivery, the other focussed explicitly on application for 'true' self-build, including the construction of a prototype. Both approaches have potential to be utilised in rural and edge of settlement locations, but each approach warrants different materials and techniques.

Section 5 reports on the ongoing construction of two pilot projects, employing the two distinct approaches. Observations are made around the effectiveness of each approach, and the potential for further development, optimisation and future implementation.

Finally, section 6 draws conclusions from the research work. Conclusions describe the potential of alternative approaches to increase the capacity to build quality new housing in the UK, the barriers and incentives affecting the uptake of new approaches, and the potential of alternative approaches to deliver wider benefits – particularly for future generations. Opportunities for further work in the future are also identified.

2. Introduction

2.1 no silver bullet

> *There is in fact no such thing as the future, singular; only futures, plural.*
> *There are multiple interpretations of history, to be sure, none definitive, but there is only one past.*
> Niall Fergusson, Civilization: the West and the Rest (2011)

There is a tendency among housing providers and policy-makers to search for a silver bullet – an ideal housing solution – that will consistently deliver the optimum balance of quality, efficiency and affordability. However, the central thrust of my MORE | BETTER publication, an investigation of alternative approaches to housing delivery produced for Welsh Government in 2016, is that there is no such single solution:

> *Analysis of a range of case studies, combined with commentary from expert contributors, concludes that there is no single 'silver bullet', but that there is potential for more, better housing through a combination of innovative delivery pathways and construction techniques.* (Green with Forster, p.5)

The most appropriate housing designs, materials, methods and delivery pathways for any given situation will be influenced by a wide range of factors including (but not limited to) geography, climate, context, end user and delivery partners. Some of the potential benefits of different approaches relate to project delivery (e.g. affordability, reduced site time, fewer defects). Others relate to the development 'in use' (e.g. reduced fuel bills, lower carbon footprint, energy generation). Further benefits have potential to impact on the wider context (e.g. support for local supply chain, community socio-economic benefits). For a summary of these potential benefits, see figure 2.1, overleaf.

Most significantly, to truly increase the amount and quality of homes being built, it is essential that greater diversity of approaches is encouraged (thereby building more capacity to deliver homes to a better standard) rather than less.

Figure 2.1

The WikiHouse system is an example of an emerging alternative approach, made widely available through an open source protocol, utilising plywood as the core material, and virtually eliminating skilled labour.

Photo: Farmhouse, Rugby (WikiFoundation, 2016)

The same premise remains the central tenet of this piece of work; that diversity of approaches is a key component of a successful national housing delivery strategy. The research described by this paper takes a single concept design for a new home or homes in a rural context, and optimises the detailed design of the concept to suit two different types of project delivery (one project that is contractor-led, the other a 'true' self-build approach). This paper then reflects on the incumbent differences between the two approaches. By doing so, the research should reveal the significance and relevance of difference in alternative approaches to housing delivery, and the importance of a national housing delivery strategy that does not adopt a 'one size fits all' approach.

Figure 2.2 Visualisation of a social housing scheme utilising the *Barnhaus* concept, demonstrating how it sits successfully in a rural or edge-of-settlement context (2015)

This introduction serves two purposes:

Section 2.1 describes the context for the research work that was undertaken, explaining three key drivers behind the underlying design work.

Section 2.2 provides an account of the timeline for the research. It explains in outline the different components of the work, including the way in which they are interconnected and relate to distinct approaches to delivering houses in rural locations.

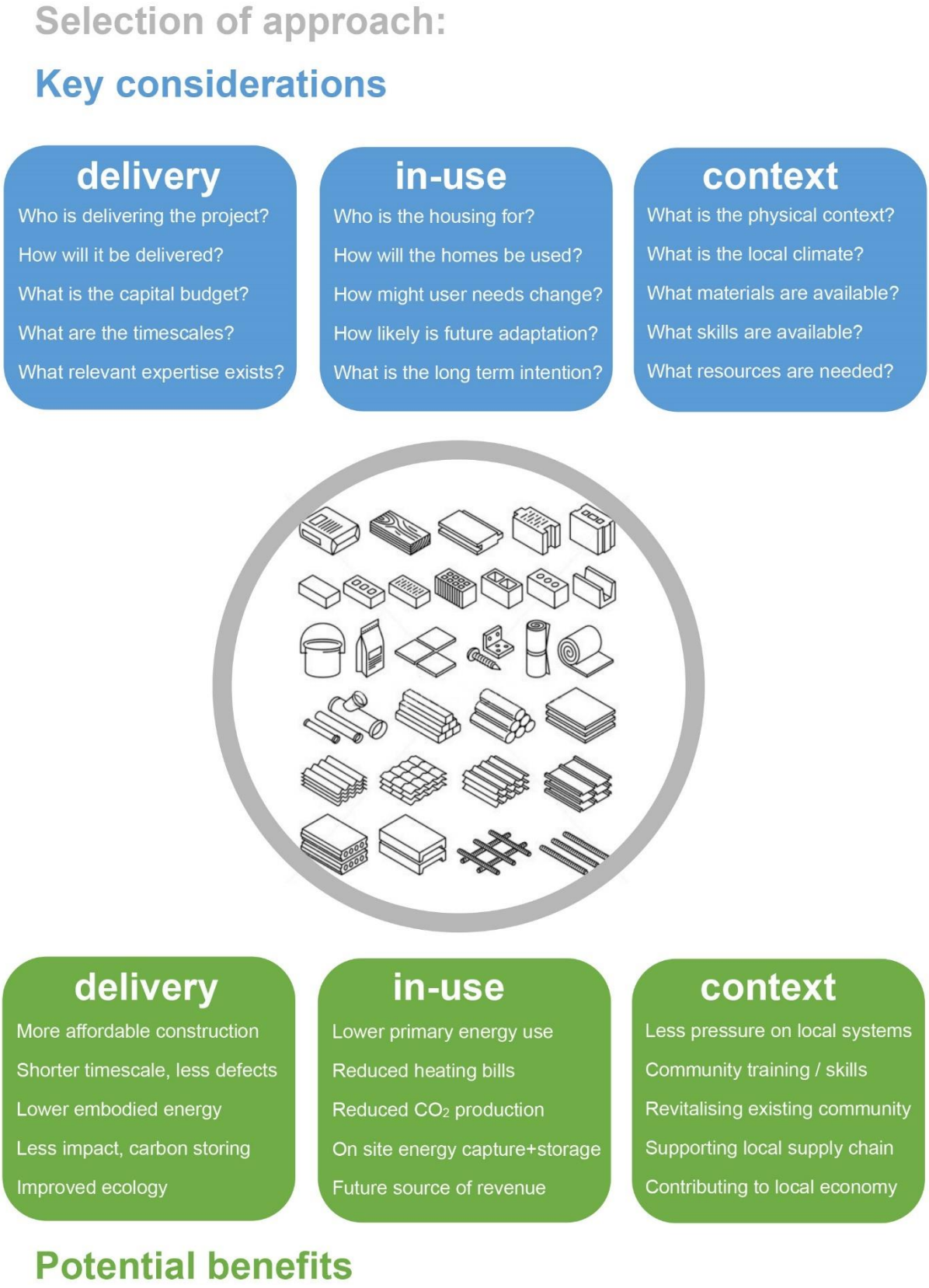

Figure 2.3: constraints and potential benefits of different approaches to housebuilding (from *MORE | BETTER: an evaluation of the potential of alternative approaches to inform housing delivery in Wales*, Green with Forster (2016)

2.2 MMC, self-build and the rural context

There were three key catalysts for research that informed the development of the Barnhaus concept and provide the context for the research to be understood:
[a] a contemporary drive within the UK for the self-build sector to deliver more new houses
[b] the potential of MMC (modern methods of construction) to deliver better performing homes more efficiently
[c] the need for alternative approaches to house design and construction that can deliver homes that are more appropriate to a rural context than established methods and models.

[a] The drive for self-build

In 2013, UK Communities Secretary Eric Pickles launched a series of initiatives designed to incentivise the self-build housing sector. This included the requirement that all English Local Authorities measure demand for self-build, and make provision of sites to meet that demand (NPPF, paragraph 159). A £30m Custom Build Investment Fund (CBIF) was initiated to encourage custom-build developers and the Locality fund was established, offering £17m of community-led project support, to nurture self-build collectives and community-led groups. Evidence suggests appetite for self-build is burgeoning (NaCSBA, 2014).

"There are over 50 councils supporting self-builders – by making land available or supporting individuals and community groups with their schemes and there were 11,000 custom-build projects last year. That's around 1 in 10 of all the new houses in the country - a £4billion boost for the national economy… We believe we can go further - that with support and nurturing the custom-build industry can double in size over the next few years. We can make this a mainstream option not a minority interest."
Eric Pickles, quoted on UK Planning Portal 23.10.2013

[b] MMC

A succession of reports including *Reaching for the Skies* (1934), *the Simon Report* (1944) and *the Barnwell report* (1967) highlight how, for many years, the UK construction industry has been considered wasteful and inefficient compared to other industries. While these reports largely failed to gain traction, more recent publications - notably Latham's 'Constructing the Team' (1994) and the Egan's 'Rethinking Construction' (1998) rekindled a desire to translate learning from manufacturing into a construction industry described as 'ineffective', 'adversarial', 'fragmented' and 'incapable of delivering for its customers' (Latham, 1994).

In the two decades since Egan, considerable time and money have been invested by a wide range of stakeholders in explorations of modern methods of construction (MMC). However, throughout the same period, increases in the regulation of environmental performance have been modest (with an effective 8% increase in performance requirements between Building Regulations Part L1(domestic) 2010 and Building regulations Part L1(domestic) Wales 2015). This has diminished the incentive to explore new approaches to housing delivery, and enabled a 'business as usual' model to prevail throughout the housebuilding industry.

In 2016, the findings of the Building Performance Evaluation Programme were published by InnovateUK (Palmer et al. 2016). The programme was a four year, £4million piece of research exploring performance across the construction industry, with a focus on residential projects seeking to meet lower carbon aspirations. Findings focussed on that the gaps between theory and practice, the reality of aspiring to higher standards, and challenges

associated with integrating new technologies. In concluding findings, the authors observed that "…there is no way to meet the Government's 80% carbon reduction target by 2050 without a revolution in the way we construct and run buildings."

Figure 2.4

Murray Grove (1999) was the first housing project to use steel framed modular construction to improve the quality of affordable homes to rent, and radically reduce time on site. The project was handed over with zero defects, and was on site for just six months, half the predicted programme time for traditional construction methods.

Photo: Cartwright Picard, 2000

[c] the rural context

A need has been identified within the UK as a whole, and Wales in particular, for affordable rural housing. If there is a distinctive architecture of Wales it is the vernacular dwelling in the landscape. In recent times, traditional sensitivity to site, orientation, form and use of local materials has been sacrificed in favour of economy at all costs, and the resulting proliferation of generic placeless developments. As a result, there is a clear need for approaches to designing and constructing dwellings that are affordable and efficient, but that suit the rural and edge of settlement contexts prevailing throughout Wales.

3. Concept

In the summer of 2013, Grand Designs and the National and Custom Self Build Association ran an international competition to design an affordable family home, to be built using non-traditional methods. The *Self Build on a Shoestring* competition (NaCSBA, 2013) was intended to encourage the dissemination of new ideas for housing and to promote self-build and custom-build markets. The brief called for “entrants to come up with innovative, sustainable and good-looking ways of self-building a typical home for a family of four.” Judges included Kevin McCloud and Charlie Luxton, the Mayor of Bristol George Ferguson (a former president of the Royal Institute of British Architects) and the chair of NaCSBA, Ted Stevens. All competition submissions were required to include a detailed cost report demonstrating that the house could be constructed for less than £50,000 (not including labour other than specialist input where required by law), along with sufficient visual material to accurately describe the characteristics and qualities of the resulting dwelling. The *Barnhaus* concept was developed in response to this brief.

3.1 the Barnhaus concept

The *Barnhaus* concept draws from the simplicity and economy of agricultural structures. Low cost, off-the-shelf components are used to form the basic structure and envelope of a house. However, they are combined in a way that makes it easier to achieve significantly higher thermal performance than currently required by Building Regulations, without complex detailing or specialist products. The conceptual aspiration is for a house design that is simple to build, appropriate for rural or edge of settlement locations, easy to maintain, and consumes a minimum of energy.

The concept relies on a simple portal frame to generate the space for the new house, manufactured on-site or off-site to a high level of accuracy, and then erected in a single day. This space is then clad in a highly performing thermal wrap, which can also be fabricated off-site and assembled on site in a matter of days, delivering much higher standards of airtightness than are typically achieved with conventional ‘bricks and mortar’.

Figure 3.1: a cut away section illustrating the benefits of the frame, from the original competition entry

Although there is no universal definition of ‘off-site’ construction, there are clear shared benefits to systems that fall into this type of construction, including better working conditions, higher delivered quality, and greater control over the build programme. A key to wider applicability of such an approach, however, is limiting the specialist skills involved, such that the workforce can be drawn from a broad sector of the working population.

Simplicity is therefore a central theme of the design. The portal frame encloses the volume of space required for a house as efficiently as possible. The frame sits lightly on the ground, minimising site work and foundations. By wrapping the majority of the frame in a simple envelope with as few penetrations as possible, higher levels of insulation are made easier to achieve. The simple form and lack of wet trades make it easier to achieve a better standard of airtightness, as a shorter build programme. These aspects of the design also make it possible to involve unskilled workers in a wide range of construction phases, and to train and build teams within a new or existing community.

The RIBA commissioned public survey ‘The Way We Live Now’ (RIBA/Ipsos Mori, 2012) identified lack of flexibility and shortage of space as being core issues with modern UK house building. The simple form and structural frame mean that the *Barnhaus* design can be adapted or extended easily, making it more responsive to changes in use patterns, and more likely to provide a long term solution for households whose needs change over time. Internal partitions are all lightweight to minimise wet trades, and lined in plywood to create a visually warm interior that is easy to service and adapt, and to avoid the need for plastering.

In environmental terms, the design aims to achieve the highest level of performance possible without compromising the construction budget. Recent government pilots have revealed the heavily inflated costs required to achieve Code for Sustainable Homes levels 5 and 6 using ‘bricks and mortar’, without this standard necessarily delivering buildings that consume very low levels of energy in use in practice. The Barnhaus design aims to provide a practical approach to driving down energy consumption and carbon production with a construction methodology that is healthy, breathable, adaptable in the long term, and maximises use of local resources - see graph, figure 3.2, below.

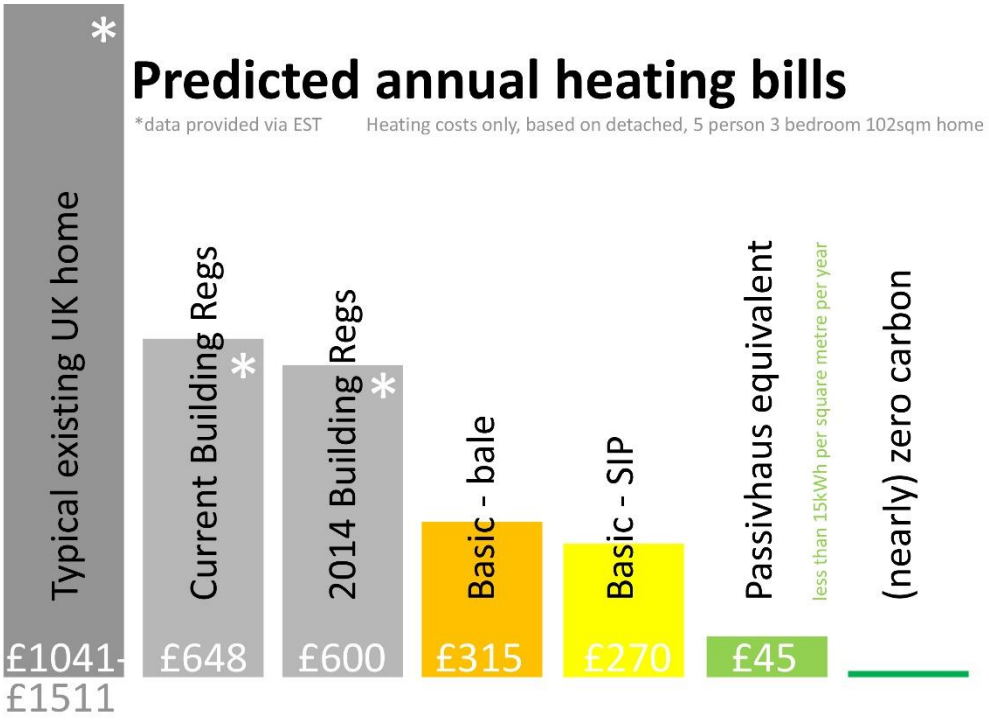

Figure 3.2: comparison of annual fuel bills for a Barnhaus-constructed home (orange, yellow, green) compared to typical existing housing (EST data, 2016) and Building Regulations compliant homes.

Most importantly, by simplifying the construction of the building envelope, the ever-present gap between anticipated and measured performance should be diminished (Zero Carbon Hub, 2014). The high levels of insulation within the envelope mean that a single point heat source – a conventional wood burning stove – should provide plenty of heat for the entire house. The design of the building maximises natural resources and ensures a controllable environment that will not overheat. Roof mounted solar thermal panels would preheat hot water, topped up by a back boiler on the wood burning stove and stored in a solar hot water cylinder to provide thermal storage. Excess heat can be distributed through heated copper pipe rails in the bathrooms, airing cupboard and coat store. A simple, appropriately sized system such as this would deliver dramatic cost savings over a conventional wet central heating system.

With the addition of deeper insulation, an MVHR system and careful attention to detail, dwellings could be constructed using the *Barnhaus* approach to meet more onerous performance standards, including the increasingly popular Passivhaus standard or more forward-thinking aspirations for nearly-zero carbon construction.

DISSEMINATION

The *Barnhaus* concept was announced as overall winner of the *Self-build on a Shoestrong* design competition within the Grand Designs Live exhibition at NEC Birmingham in September 2014. Subsequently details of the winning design were published in the national / international press, including articles in the Architects Journal, Daily Mail, Wales Online, NASBA website, plus coverage oversesas (Yahoo Finance – UK, Spain and Romania, and Natural Building Blog, United States), and via organisations including CIOB, CITB, FMB and DCfW. On 06 November 2014, evidence was provided for Welsh Government Ministers as part of a housing enquiry (WG 2014). See timeline for more details.

3.2 Timeline - concept

Key milestones in CONCEPT DEVELOPMENT:

Prior to 2013	Experience of both contractor-led projects and self build construction informed the development of the Barnhaus concept.
Summer 2013	High quality low cost housing concept for rural locations developed for international design competition, with a focus on self build.
October 2013	National competition winner, presented at Grand Designs Live National / international press coverage, including articles in the Architects Journal, Daily Mail, Wales Online, NASBA website, plus coverage oversesas (Yahoo Finance – UK, Spain and Romania, and Natural Building Blog, United States)
November 2013	Workshop organised by Design Commission for Wales to Welsh Govnt, Local Authorities and RSL's.
December 2013	Given as evidence to Welsh Government housing enquiry
January 2014	Articles in MasterBuilder journal, FMB & Construction Manager News, CIOB
January 2014	Seminar, Interiors UK national conference, NEC Birmingham
February 2014	Discussion with Welsh Government Housing Minister Carl Sergeant
May 2014	Seminar, Grand Designs Live, ExCeL, London
July 2014	Presentation, Shelter AGM
July 2014	Shortlisted for UK CES grant funding (unsuccessful)

Design team:	Pentan architects (led by Ed Green)
Client:	NaCSBA (National Custom and Self Build Association) Grand Designs / Media10
Support from:	FMB, CIOB, CITB

4. Development: two approaches

In the three years that have passed since the *Barnhaus* concept won the competition, there have been a number of attempts to deliver it on site, with a range of different partners. Despite more than two hundred approaches from prospective clients, as a practice Pentan architects took the view that any potential pilots should be approached with caution. This was primarily to reduce the level of risk that the practice was exposed to, by severely limiting the number of projects being delivered using a previously 'untried' method. As a result of this cautious approach, there have only been two projects completed to date using the concept; a social housing project of four dwellings delivered by a main contractor (approach A, project A) and a single self-built dwelling (approach B, project B). Once these projects have been properly monitored and evaluated, and reflected upon, the intention is to develop the design thinking further, and consider how best to deliver more *Barnhaus* projects at a range of different scales.

The following section explains the process of taking a single design concept (from the competition) and developing it into two distinct detailed design proposals, for two different client types, using two different approaches to delivery, in two very different contexts, as outlined in the table below:

	Project A	**Project B**
Client	Valleys to Coast Housing Association	Private household
Location	Pyle, Bridgend	Pantygasseg, nr Pontypool
Dwelling type	4 detached homes, each of which is a 2 bedroom 4 person social housing dwelling.	Detached 2 bedroom dwelling located in pre-existing historic stone structure
Standards	Building Regulations (Wales 2016), DQR (Welsh Government's development quality requirements), Lifetime Homes (accessibility good practice)	Building Regulations (Wales 2016) Off grid context.
Dwelling size	95sqm per dwelling	
Key aspirations	The client is looking for an approach that can deliver affordable, high quality social housing at a range of scales. They typically deliver homes in geographic locations where many housing contractors are unwilling to operate, due to diminished profit margins. The aspiration for higher environmental standards is driven by the desire to reduce fuel bills. The client's prior experience of (post war) housing innovation has led to concerns around potential maintenance costs.	The client wanted to realise a modest family home on a tight budget using 'healthy' / breathable building materials. The dwelling was to be built high environmental standards, particularly in the thermal envelope, to minimise fuel bills. It was necessary to adopt a conservation approach to the existing stone superstructure, which is at least two hundred years old and establishes the maximum footprint for the dwelling as well as part of the aesthetic. Overall height was also limited by planning.

Table 4.1: comparative summary – project A and project B

4.1 approach A - contractor-led

The Barnhaus concept was presented to Valleys to Coast Housing Association's board of trustees, and the board elected to support a pilot project on a site owned by the HA, within an established community in North Cornelly, Bridgend in South Wales.

The pilot project consists of four social housing dwellings. The homes are identical (see house layouts below and site layout, overleaf) apart from the construction, which will be varied to explore two different methods of insulation. The housing association are also acting as developer / employer for the project, and take responsibility for occupying and maintaining the buildings long term.

Each house is compliant with both Welsh Government Development Quality requirements (DQR, 2005) and Lifetime Homes standard. By exploring different options for insulation, the pilot project facilitates a comparative study as follows:
Two homes to be constructed from steel frame with straw bale insulation
Two homes to be constructed from steel frame with blown fibre insulation.

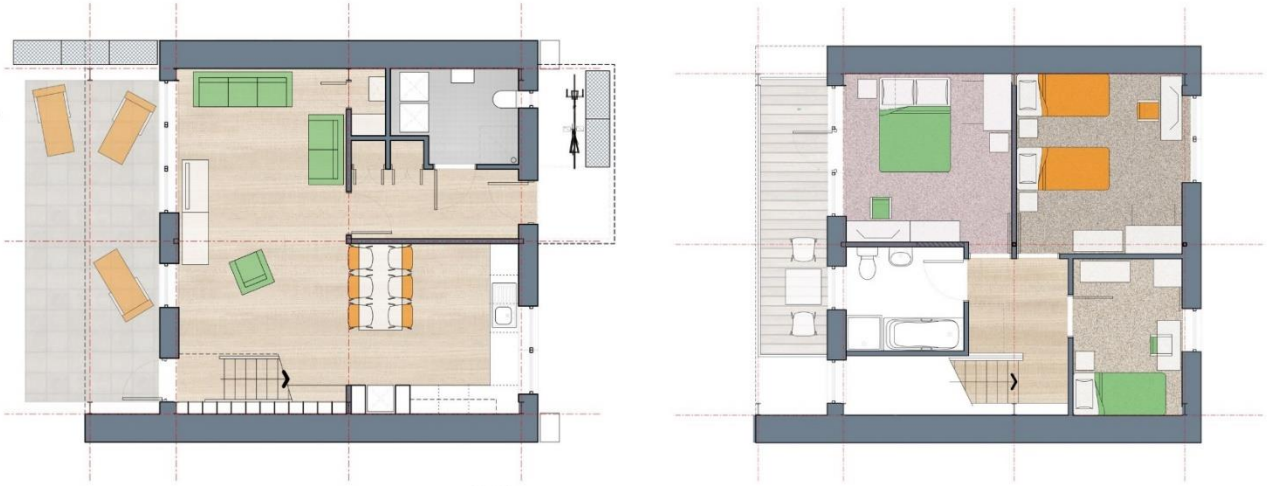

Figure 4.1: DQR compliant three bedroom five person dwelling layout

The pilot project is intended to explore the following key aspects of the approach:
• Energy / carbon consumption (as predicted versus as delivered)
• Workmanship on site / buildability
• Thermal performance (post completion analysis of envelope)
• Capital costs (as delivered)
• Running costs (in use)
• Occupant interface (in use)
In addition, a key objective for the *Barnhaus* approach is to maximise the training opportunities associated with a simplified construction system. Housing associations are particularly interested in tenant and community involvement in the building process, and in the potential to train users during the process, and leave them with transferrable skills.

The subsequent sections explain the social housing pilot project in more detail:

SITE STRATEGY
The dwellings have been designed and arranged to take advantage of their site as well as maximise density, while respecting the scale of the surrounding neighbourhoods. Four dwellings are arranged in a simple row to create a new street 'frontage' along the pedestrian route connecting Plas Morlais to the neighbourhood to the north.

The dwellings are located sufficiently close to create a sense of community, and are pulled forwards to engage with the public realm and minimise the degree to which they must cut into the site. They expose their side walls to the busier public areas - the pavement along Plas Morlais and the public right of way along the northern site boundary. The roof forms oversail the dwelling frontages and offer a shared sense of enclosure – bringing a human scale to the openness of the landscape beyond, offering protection and shelter.

For the individual dwellings this orientation permits level access into the properties at both the front and rear entrances and ensures accessibility for all. Windows face largely East or West, and no rooms are oriented to the North. As a consequence, the main living spaces all benefit from good natural daylight and long periods of solar gain throughout the day. This reduces the need for artificial lighting and space heating.

Figure 4.2: A visualisation of the social housing pilot project in Bridgend, currently on site

FRAME

The structure for the contractor-led approach is provided by a steel portal frame, with the intention that this approach takes advantage of off-site fabrication to manufacture a frame that is precise, easily replicated and can be erected in a matter of days (approximately two days per dwelling). Arranged at wide centres (around 3metres from one frame to the next) the frame also minimises the amount of groundwork required to negotiate poor ground conditions or steeply sloping topography, neither of which are uncommon on sites typically available for social housing in South Wales.

The starting point for this structure was the steel portal frames used for agricultural and storage units worldwide, providing free space at a minimum of cost (approximate cost for a dwelling-sized frame is around £2500). However, regulations governing domestic structures are different from agricultural structures (particularly regarding deflection) and the additional stiffness needed for the domestic frame dramatically increases frame member size and rigidity, and consequently cost. Manufacture of the frame involves fabricators who do not typically contribute to housing production. However, the cost of overheads and haulage in particular mean that this approach would be increasingly economic if delivering housing at

scale. Current pricings place the cost of the ‘standard’ domestic frame at around £9000, making it critical that benefits are gained by utilising this approach.

The frame oversails the house at one end and provides a covered outside space, a natural extension of the generous, flexible space indoors, and protects from overheating. By expressing the frame internally, the house remains easy to extend or adapt in the future.

In adapting the design of the original concept to meet the needs of a social housing client, the suspended timber ground floor was replaced with a solid floor construction. This was to provide fully accessible dwellings via a level threshold (an important aspect of Lifetime Homes) and to eliminate key maintenance concerns. The cost implications for this change are considerable and diminish the cost effectiveness of the approach, particularly on sites where ground conditions are poor and simple pad foundations represent an ideal solution. However, the additional cost was considered less problematic than the risk of maintenance issues and concerns over robustness.

ENVELOPE

Engineered timber wall joists generate a deep building envelope and facilitate higher standards of energy efficiency utilising sustainable, locally available insulation such as straw bales or blown fibre. Straw bale construction, for example, reaches U-values in excess of 0.15 W/sqmdegC, and is highly sustainable as the straw sequesters significant amounts of carbon within the envelope. Whilst straw bale construction is becoming more accepted practice in the United States (where it is now incorporated into national Building Codes) it is still a relative rarity in the UK, and the benefits are not widely appreciated (BRE Information Paper IP15/11). The proposed use of straw bale generated client concerns over condensation and infestation which were difficult to refute due to the limited track record. Blown fibre is more widely used as an insulant with some of the best environmental credentials, and its lightweight, flexible characteristics make it suitable for this approach.

Alternatively, SIP construction allows for a further element of the Barnhaus system to be off-site fabricated, extending the benefits of the frame approach (quality, reduced overheads) to the building envelope. The SIP panels form roof and external walls, and have potential to be used as envelope only (ie with the frame) or structurally (ie without the frame). Some SIP manufacturers are willing to guarantee a high quality baseline airtightness, which reduces the risk of achieving higher standards. The same locally grown, small section timbers can be exploited throughout the design, with the same potential to maximise the use of locally available resources and minimise associated transportation.

The envelope is, in turn, clad in a rainscreen. This rainscreen cladding could be brick, slate or timber… The example shown uses corrugated fibre cement cladding which is lightweight, cheap and sustainably sourced. There are no windows, doors or other penetrations in the external wrap, to simplify construction and so that houses can be arranged in rows, or on tight sites. All windows are north or south facing. On the north side, openings are small and the extended frame provides support for direct solar and PV panels, a car port, waste and recycling storage. On the south side, openings are much larger and the frame provides a generous overhang, creating a sheltered terrace and covered balcony that will not overheat and could be transformed in one simple move into a beautiful sun space.

SERVICES

The client’s concerns over the thermal performance the finished product and the ability of end users to understand alternative systems mean that the intended single point heat source – a conventional wood burning stove – is replaced with a conventional (and potentially oversized) wet central heating system. This further diminishes the cost effectiveness of the approach, and makes it likely that heating systems will not be running at maximum efficiency.

4.2 approach B - self-build

A PILOT SELF BUILD PROJECT

The first pilot self-build project surfaced in 2014, when a client enquired about the possibility of constructing a *Barnhaus* dwelling at the edge of a small settlement in Aberdeenshire.

The modest site is located on the south-west edge of the small village of Benholm, near Johnshaven. It is bordered to the west by a road and farmland, and to the north by a stables, and an extensive steading with planning approval to be remodelled into dwellings. To the east of the site lies countryside and more agricultural land.

A two bedroom house was developed for the site, using the Barnhaus concept. External storage and car parking were to be provided in a hard landscaped area between the house and the stables to the north. The house was designed to achieve level 5 of the Code for Sustainable Homes, while maximising the use of locally sourced materials. The client, a single parent mother, intended to carry out much of the construction herself, with support from friends and relatives. To fit with the grain of the surrounding settlement, the new dwelling was to run from NE to SW on the site, with a relatively enclosed north-east 'front' facade, and a much more open 'rear' elevation to the south-west. The sides of the dwelling were to have relatively few openings, to maintain simplicity of construction and an agricultural aesthetic.

A Planning application was submitted in April 2014, and approval granted in summer of the same year. A Buildings Warrant (Scottish Building Regulations) package was then compiled, but the time and cost involved in identifying and employing a structural engineer to design the steel frame were counterproductive. Finally, the cost of bringing mains electricity to the site (a client requirement) proved prohibitive, and the project was aborted end of 2015.

While developing this pilot self-build project, it became clear that aspects of the original Barnhaus concept were acting as barriers to its application for self-build projects more generally. For a home to be widely applicable to the true self-build market (i.e. projects whereby the dwelling is to be physically constructed by the end user), specialist skills must be eliminated. Materials should be widely available, and component sizes manageable. But most importantly, the concept must be sufficiently flexible to suit different needs, and the design must be adaptable enough to respond to different contexts and locations.

DESIGN DEVELOPMENT – A FURTHER COMPETITION

During the summer of 2015, the *Barnhaus* concept was developed more specifically as a self-build approach, under the guise of a further competition. The competition brief required designs for small, economical self-build-friendly dwellings, and provided an opportunity to reconsider the original concept, by focussing on the true self-build market.

The steel frame and straw bale of the original concept were replaced with a timber portal frame and two-way timber stud outer envelope, to eliminate steel from the construction and utilise only standardised off-the-shelf components that are available from any builder's merchant. By assembling smaller components in a repetitive fashion, flexible modules are created that can be arranged in near endless variety of ways. Elimination of the steel frame also replaces high embodied energy components with a material that sequesters carbon.

As with the original concept, simple pad foundations support the portal frames – now built entirely of timber, and moveable by just two people. Together, these frames generate

generous spaces, unencumbered by internal structure and open to the rafters. No loadbearing internal structure means that the home can be as open plan or private as residents desire. The material costs for the structure of a basic dwelling of around 70sqm are less than £1000, and the superstructure can be fabricated and erected by just two people on- or off-site in a single week.

The thick external skin is now built up of two layers of timber stud running perpendicular to one another, outside of the primary frame, in lieu of the more specialit wall suds. This allows for a wide range of insulation products to be employed - including straw bales, recycled straw products, sheeps wool or recycled paper - and eliminates thermal bridges, enabling the highest levels of thermal performance. A difficult connection between steel frame and timber skin is also eliminated. Externally, the skin can be clad in any number of lightweight rainscreens, to suit the local palette of materials, or to stand out from its surroundings.

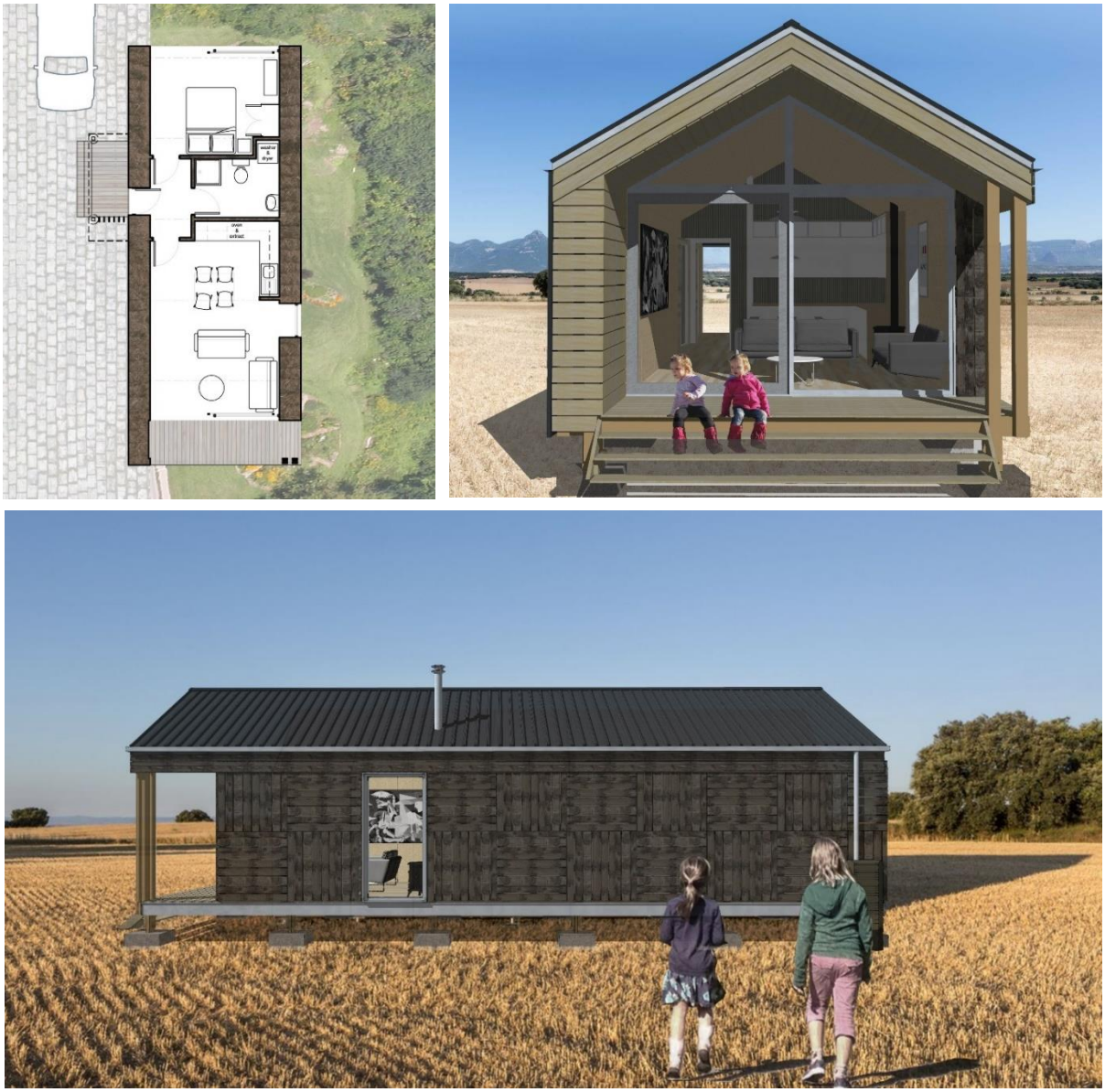

Figure 4.3: revised approach B lends itself to simple forms and modest dwellings.

By simplifying the constructional makeup and eliminating specialisms such as wet trades and steel fabrication, construction of an entire home becomes realistic for first time self-builders as well as experienced professionals. Skilled labour is only needed for the electrical circuitry, mechanical ventilation, and any renewables, which must be installed by an

approved subcontractor. Due to the high levels of insulation within the envelope, a single point heat source – a conventional wood burning stove – provides plenty of heat for the entire house, dramatically reducing the cost and complexity of the heating system required. The design of the building maximises natural resources and ensures a controllable environment that will not overheat. Roof mounted solar thermal panels are to preheat hot water, which is topped up by a back boiler on the wood burning stove and stored in a solar hot water cylinder to provide thermal storage. Excess heat is distributed through heated copper pipe rails in the bathrooms, airing cupboard and coat store.

A ‘basic’ design of just 42sqm floor area was developed, as a starter home for a single person or a couple. The predicted cost of this starter home (assuming good ground and ‘basic’ materials) was just £27,000 (excluding labour, other than the subcontractors listed above). A further example uses two of the basic forms side by side, to create a generous three bedroom family home of 92sqm GIA, organised around a central courtyard.

A BUILT PROTOTYPE

Further design development took place just under a year later in the summer of 2016, when an opportunity presented itself to build a prototype for the self-build approach at the Centre for Alternative Technology (CAT) in Machynlleth, and then take it to Glastonbury festival.

The pavilion was conceived as half of a dwelling using the revised self-build *Barnhaus* concept. Structural engineers Momentum assisted in refining the structural concept. It was then prefabricated over the course of a week at the Centre for Alternative Technology (CAT) by two staff members working in conjunction with a group of unskilled students.

The finished pavilion was then broken down and transported to the Glastonbury festival site, before being erected on a standard festival plot over a 48 hour period. Located between two festival stages, it provided an example of what can be achieved with an ecological, people centred approach to construction. Inside, festival-goers met staff and students, and had conversations about environmental and ecological design, and ways of building better. As an interactive exhibit, it was designed to explain the key features of the *Barnhaus* self-build concept, and demonstrate how construction of this type could help people with limited resources other than their own labour to improve their own environments.

Figure 4.4: Prototype under construction at CAT and onsite in the Green Futures Field, Glastonbury

4.3 Timeline - development

Key milestones in DESIGN DEVELOPMENT – TWO APPROACHES

	Approach A – contractor	Approach B – self build
Jan-April 2014	HA solution developed based on extensive prior social housing experience	Development of client-specific solution for single household, Aberdeenshire
April to July 2014	Concept presented to V2C Board, approval obtained to progress a 4 dwelling scheme within an existing housing estate. Planning application submitted (Aug)	Planning application submitted (April)
August to Nov 2014	Planning application obtained (Sept). First outline costing including comparison with conventional build (Nov)	Planning approval obtained (Nov)
January to April 2015	Working drawings developed for two parallel approaches – straw bale infill and SIPs construction.	Building warrant package developed to satisfy Scottish Building regulations
May 2015 – Feb 2016	Working drawings package complete. Costings updated. Value Engineering takes place due to high levels of site-related abnormals escalating costs.	Structural engineer identified. Construction package developed, including fully designed and costed structural frame / superstructure.
March 2016		Project placed on hold indefinitely due to high cost of bringing energy supply to site.
April to June 2016	Project placed on hold short term due to predicted total cost, pending further review.	Prototype timber structure developed in conjunction with Momentum engineering. Fabricated and constructed at CAT, then dismantled and taken to Glastonbury festival.

Design team:	Pentan architects (Ed Green) RPA Cost Consultants Cambria Structural engineers	Pentan architects (Ed Green) Momentum structural engineers
Client:	Valleys to Coast Housing Association	Private client
Support from:	Morgans of Usk fabricators CHCC	Staff and students at the Centre for Alternative Technology (CAT)

5. Delivery: two projects

In the three years that have passed since the *Barnhaus* concept was first developed, the process of progressing from a single concept design through to three delivered projects on site (including the prototype structure for Glastonbury festival) has been painfully slow.

Initially, as outlined in Section 4: *Development*, the hiatus came from a cautious, risk averse approach to developing the concept into site- and client- specific proposals. There were a number of false starts. Planning approval was obtained for a self-built dwelling on a rural site in Aberdeenshire (see timeline, Approach B - previous page), but the project stalled when the local energy provider demanded a large sum of money to bring electricity supply to the site. Several other projects faltered at feasibility stage, often because of unrealistic expectations around cost (despite our best intentions and honest appraisals of cost up-front). A further barn conversion project (under Class Q of the recent Town and Country Planning Order (2015) that presumes in favour of permitting conversion of existing agricultural structures into single dwellings) was taken as far as planning approval, but the client then decided to develop the project in their own direction without further support from consultants.

The primary pilot project, 4 social housing units for Valleys to Coast HA, stalled in the summer of 2016 (see timeline, Approach A – previous page). A problematic site, undeveloped for many years, generated high levels of abnormal costs and compromised the viability of the project. It was not until a year later that the Innovative Housing Programme, launched in January of that year (see CHC, 2017), provided a further source of funding and made the pilot project financially viable for the client. This eventually led to the commencement on site of Project A in early 2018.

The catalyst for progression of the self-build variant (Approach B) was the prototype structure built at CAT, and taken to Glastonbury in June 2016. This simple project provided an opportunity to develop, test and refine the structure and envelope design, with support from Momentum engineers. In turn, this work led to the commencement on site of self-build Project B in the summer of 2017.

The following section outlines how these two projects have been developed into delivered buildings:

5.1 a social housing project

Relatively early in its programme, the site identified for this project (in the ownership of the client) was recognised as problematic. The land falls away steeply across the site, pre-existing (and deep) services run across the site, and it is bounded by poor quality retaining walls – all of which add considerably to the cost of delivering the project.

Detailed cost analysis established that the alternative approach proposed for the project was not delivering poor value compared to a conventional build approach. (The use of straw bales was one element of the design that attracted additional cost, due to a lack of experience amongst all tendering contractors, as well as concerns over the availability of appropriate quality materials.) However, despite a thorough value engineering process and two separate attempts to tender the work, the abnormals associated with the site itself were deemed too costly for the client to bear and the project remained stalled at pre-construction stage for a full year.

In October 2017, the project was successful in securing additional grant funding from Welsh Government's Innovative Housing Programme (IHP), which made it financially viable for the client. Following confirmation of grant approval, the cost plan and tender was revisited during a mobilisation period, and the project commenced on site in March of 2018 (a condition of the funding).

There was a slow start on site initially, while further modifications were made to the design and the contract documents. In June of 2018 a fuller commencement of work was made, and the programme is scheduled to complete in April 2019.

The construction process is currently being monitored, in order that reporting and evaluation can take place in line with the requirements of the IHP. The client is currently in the process of identifying four 'appropriate' households to be the first inhabitants of the completed project, as monitoring and evaluation will extend for a period of three years post completion.

5.2 a self-built project

The prototype all-timber structure fabricated at CAT and then assembled as a stage at Glastonbury festival successfully tested the premise and the structural integrity of the self-build Barnhaus concept (approach B), but did not fully establish or test the method of completing the thermal envelope to achieve Building Regulations compliance.

In May 2017, an opportunity presented itself to personally construct a full dwelling using Approach B on a rural site of around 0.25Ha in a rural location outside of Pontypool. The site came with a pre-existing planning approval (renewed in 2015) to convert an existing, historic but dilapidated stone barn structure into a single storey two bedroomed dwelling. The original approval extended and adapted the existing stone structure, converting it into a shallow pitched roof form with an extended outrigger. In doing so, the clarity of a simple pitched roof form with a monopitch lean-to element was lost. A clear sense of the 'historic' stonework would also have been lost as the stonework was extended and adapted to suit the new building form. On securing the land, a further planning application was submitted, to adapt the existing approval into a proposal that has increased sensitivity to the existing building, and delivers a dwelling that meets the needs of the applicant, and performs to the highest standards of sustainability.

Using the Barnhaus self-build approach, a simple standalone pitched roof timber form now sits independently inside the stonework of the original stone structure, reinstating the pitched roof gables of the original barn. The revised proposal retains the existing stonework in its current form, which has been repaired and repointing as necessary. It contains the main bedroom, kitchen, storage and living space. The lean-to element remains as a secondary volume, containing only a bathroom and second bedroom. The work was carried out, for the most part, by two semi-skilled operatives with limited experience of construction and no specific training. According to the original concept, groundworks were kept to an absolute minimum, with ten shallow concrete pads located directly inside of the original stone structure. The frame and envelope were constructed entirely from standard, off the shelf components taken from the local sawmill, which were machined and assembled using only battery powered hand tools. All components were fabricated on site, and no heavy plant was employed during the process.

Figure 5.X

The freestanding timber portals fabricated from standard off-the-shelf components can be seen standing inside the historic stone structure on simple concrete pads.

It took two operatives three days to fabricate the primary frame, and a further two days to erect the frame and line with joists and rafters.

A number of changes were made to the design as a consequence of the historic fabric. Due to the constrained footprint, the external envelope was not insulated with thick straw bales, but with a range of straw-based insulation products. In combination these elements deliver thermal performance in excess of building regulations, and a fully vapour permeable building envelope within a 200mm insulated zone. Together with the timber frame and skin components, they also sequester considerable amounts of carbon into the construction.

The approach adopted has avoided compromising the clarity or form of the original building, and allowed it to be retained as a piece of local history for many years to come. Perhaps more importantly, it has facilitated the construction of a new lightweight timber dwelling to a high standard of thermal performance and air tightness, such that energy efficiency is maximised, and fuel bills are minimised. (The presence of the existing stone outer wall did complicate construction of the thermal envelope considerably, and also reduce the potential to maximise efficiency by using whole, uncut timber members such as floor joists, thereby increasing both cost and waste.) Local materials have been utilised from the sawmill in nearby Pontypool, and the ecological footprint of the dwelling has been minimised. The detailed design and construction processes were monitored and recorded.

The dwelling fabric is now complete and signed off, with only services and drainage currently outstanding. Once this work is complete, a post occupancy evaluation will be carried out, to accurately assess the true financial and environmental impact of delivering a sustainable dwelling within an existing building structure.

Figure 5.X: The predominantly complete external envelope, awaiting pointing of historic stonework.

5.3 Timeline - delivery

Key milestones in PROJECT DELIVERY – TWO PROJECTS

	Approach A – contractor	Approach B – self build
Prior to February 2017	Project tendered to 4 contractors, main contractor appointed. Project on hold pending detailed cost analysis.	Prototype constructed, awaiting appropriate pilot project to deliver approach B.
February to May 2017	Innovative Housing Programme launched (Feb) by Welsh Government.	Rural site obtained for self-build pilot with pre-existing stone barn structure and pre-existing planning approval.
June to September 2017	Project secures IHP funding from Welsh Government, improving financial viability.	Amendment to planning approval obtained, start on site (July), with Building Regs approval via notice.
October to December 2017	Finalisation of construction programme and re-tender with value engineered proposals.	Completion of frame and envelope, made temporarily weathertight for winter.
January to March 2018	Project commences on site.	Project on hold due to adverse weather / limited site accessibility.
April to July 2018		Recommencement of works on site, permanent weatherproofing + interior.
August to November 2018	Ongoing construction, including monitoring and evaluation. Due to complete April 2019.	Dwelling fabric complete. Building regulations signoff apart from M&E.

6. Conclusions

The experiences gained during the time that has passed between development of the original *Barnhaus* concept and delivery of projects on site have been invaluable. Some of the key conclusions drawn can be broken down into two themes as follows:

DIFFERENT APPROACHES

Different approaches each have their place in an industry that requires increasing breadth if it is to produce more, better homes.

The steel frame and SIP or engineered timber wall construction of approach A have potential to deliver cost savings and efficiencies when employed repetitively by a main contractor (principally because of impact on programme). The true extent of these efficiencies is still to be tested at scale. However, it is entirely inappropriate for a small-scale self-builder, for whom the key to economic construction is minimising the involvement of specialists and diminished labour costs.

The timber frame and smaller repetitive components of approach B certainly deliver a low cost dwelling structure and envelope, and are entirely suited to construction by a user or community group with limited skills and experience. A key to the success of this approach is availability of information and appropriate guidance at the design and procurement stages.

Different methods, as represented by approaches A and B above, build capacity for the construction of more homes, through the potential to involve individuals and organisations not normally contributing to the housing sector in the creation of new homes. A range of different approaches exist in varying stages of development, each with distinct benefits. Many of them utilise timber as a primary construction material in order to reduce the carbon footprint, and some have potential to utilise locally grown timber (TRADA Technology, 2012). A number of these approaches are explored in the publication *MORE | BETTER: an evaluation of the potential of alternative approaches to inform housing delivery in Wales* (Green with Forster, 2016).

The importance of sharing expertise cannot be underestimated. Both the steel frame of approach A and the timber frame of approach B have potential to be optimised - for performance in use, efficiency of fabrication, production of waste and assembly. However, both structures also have potential to be delivered inefficiently. Understanding the method behind the approach and the potential benefits of the approach are key to designing for a particular approach.

Different benefits will be prioritised by different project teams. Because of this, there is not necessarily a clear ‘best’ approach in any given situation. The optimum approach will be dictated by the context for the project, the needs of the end user and the priorities of the project team.

NEW APPROACHES

Any approach still in its infancy will have limits to its cost effectiveness, as there are inevitably costs associated with research and development, and a lack of any economies of scale. Mistakes will also be made along the way. Elevated costs are difficult for many housing providers (and prospective homeowners) to ignore, as good financial value (in terms of capital cost) is such an integral part of the industry’s approach to project delivery (whereas

runnings costs are considered much less stringently). Indeed, the housing market has, for many years, been so driven by a focus on capital cost that there is little (or no) space for either project-specific design or innovation.

This financial aversion to design and innovation is compounded by the fact that most housing providers are wary of alternative approaches. This is partly because many such organisations operate conservatively. It is partly because of the possibility of unknown future cost (generated by the remediation of faulty or poorly performing buildings, or by unanticipated maintenance costs). It is also partly because in-house maintenance teams operate most effectively when looking after building types they are familiar with, and tend to be resistant to the introduction of new constructions, materials and products into the stock they must maintain in the future.

In contrast, registered social landlords, housing associations and local authorities working throughout Wales are very aware of the limited contribution to new housing that is being made by conventional housebuilders using traditional methods. As a result, there are many individuals working in these sectors who, frustrated by a lack of performance from the industry's business-as-usual model, are hungry for new approaches.

FURTHER WORK

The construction of both projects is ongoing, with more still to be learnt from each process. This learning will be in the form of detailed design development that will inevitably take place as theorised construction becomes built reality, but also in terms of lessons that can more easily be translated around designing with MMC and designing for self-build. This work will be reported on as it takes place, through revisions to this report.

Furthermore, post completion monitoring and evaluation are key components of both projects, in order to maximise the potential for learning from each. For Project A (4 social housing units), a key component of the support offered by the Innovative Housing Programme is funded monitoring and evaluation by a third party with the support of the client, along with a vehicle to disseminate findings as widely as possible. For Project B (single dwelling, private client), more informal monitoring and evaluation will take place, with the private client providing full access as needed.

In both cases, this additional work stage significantly increases the potential to learn lessons from the projects. Lessons will be learnt around the two distinct approaches that have been developed for these unique projects, but also around the way that the dwellings are subsequently inhabited, maintained and adapted by their occupants.

More generally, the provision of more | better housing remains a wicked problem, both within Wales and more widely across the UK – within both regions, the contemporary housebuilding industry consistently meets only 50% of demand for new homes (PPIW, 2015), and comes under widespread criticism for paucity of quality of the end 'product' (RIBA, 2012). There is a clear and consistent limit to the capacity of the existing volume housebuilding industry to deliver new homes, that has remained largely unchanged for almost a century. In comparison, the output of the social housing sector has dwindled from almost 50% of new homes to nearly nothing. Alternative approaches are clearly needed that build new capacity to deliver more new homes using other stakeholders, and build on the existing capacity of the volume housebuilding industry rather than seeking to substitute or replace it.

This in turn suggests that approaches using different resources (such as materials) and different people (with alternative background / skills / experience) are more likely to achieve

this goal. In tandem with this observation, it seems essential that current housebuilding practice is reviewed, to encourage better use of traditional, current and emerging methods.

Wales now has a unique piece of legislation (the Wellbeing of Future Generations (Wales) Act 2015) requiring that public bodies think holistically about all future decision making, and demands a focus upon medium term gain rather than short term expedience. The seven 'goals' of the Act are translated into specific potential benefits that might be associated with alternative approaches to housing delivery below:

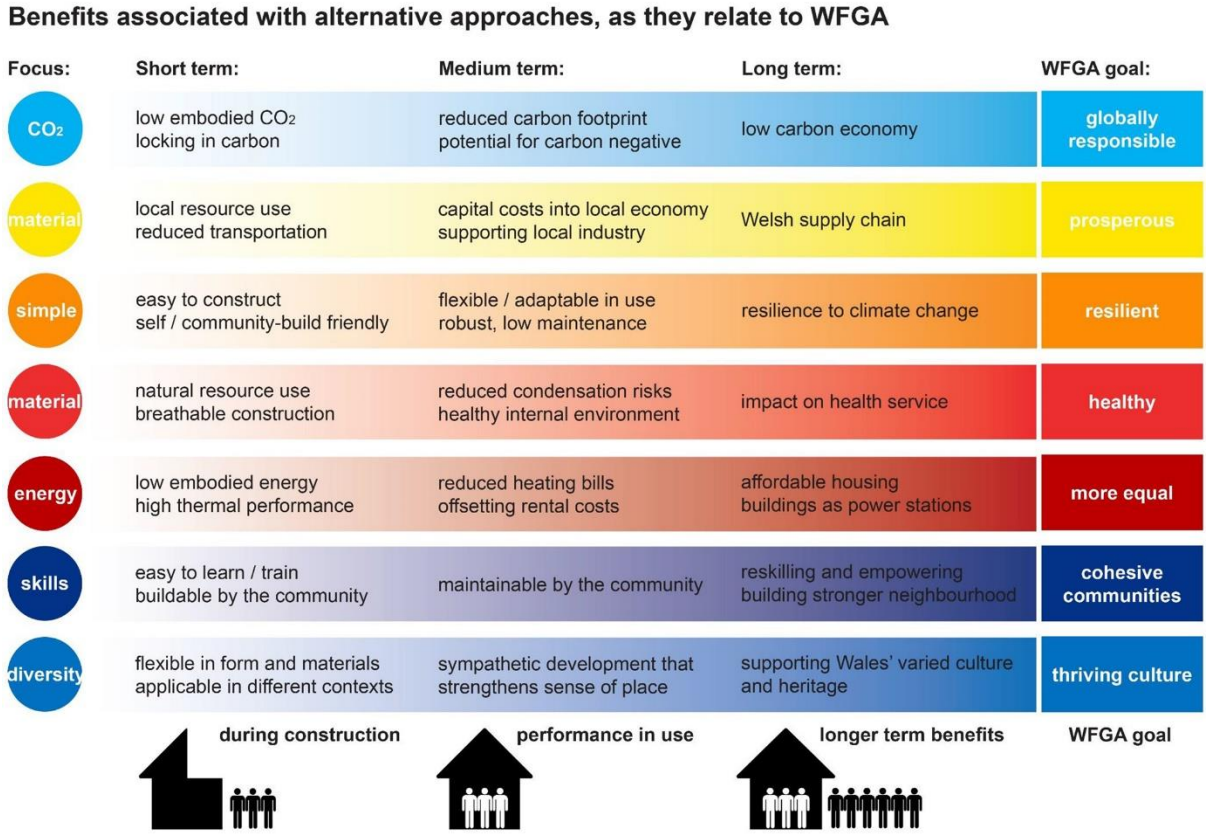

Figure 6.1: the seven goals of the Wellbeing of Future Generations (Wales) Act 2015 (LHS), translated into focus areas (RHS) and benefits associated with alternative approaches to housing delivery in the short, medium and long term. From Green, E (2017) *MORE VERSUS BETTER*

The Act mandates that the overarching aim must be to ensure that we are building the best homes we can build, as effectively as we can manage, in a way that benefits both individual communities and society at large as holistically as possible (WFGA 2016). By exploiting a range of alternative delivery pathways and construction techniques, we could be constructing new homes and neighbourhoods in a more contextually appropriate way, with greater long term value. If Wales is to rise to the challenge of the housing crisis by constructing a legacy of homes that future generations consider to be a blessing and not a burden, the correct standards, incentives and monitoring must be put in place to encourage a range of existing alternative approaches, along with some that do not yet exist, to produce more, better housing.

Ed Green November 2018

7. References

CHC (2017) http://chcymru.org.uk/en/view-news/20m-funding-for-innovative-housing-solutions

Egan, J (1998). Rethinking Excellence. London: The Construction Task Force http://constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf

Green E. with Forster W. (2017). More | better*: an evaluation of the potential of alternative approaches to inform housing delivery in Wales* (report). Cardiff University http://orca.cf.ac.uk/98055/

Green, E (2017) MORE VERSUS BETTER: exploring the tension between quality and quantity in housing, and the opportunities offered by alternative approaches, conference paper: PLEA design to thrive

House of Lords (2016) *Building better places* (report), https://goo.gl/yGBLH7

Latham M (1994) *Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry.* London: HMSO http://constructingexcellence.org.uk/wp-content/uploads/2014/10/Constructing-the-team-The-Latham-Report.pdf

NaCSBA (2013) http://www.nacsba.org.uk/12-shoestring/39-shoestring2013top16

NaCSBA (2014) *Survey of self build intentions*, IPSOS MORI https://goo.gl/dJjOww

Palmer J, Godoy-Shimizu D, Tillson A and Mawditt I (2016) Building Performance Evaluation Programme: Findings from domestic projects. Swindon: InnovateUK (TSB) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf

PPIW (2015). Future Need and Demand for Housing in Wales. London: E&F Spon Ltd https://goo.gl/pSCb9x

RIBA / IPSOS MORI (2012) *The Way we Live now* (report), https://goo.gl/ShOjid

Town and Country Planning Order (General Permitted Development, England 2015) http://www.legislation.gov.uk/uksi/2015/596/schedule/2/part/3/crossheading/class-q-agricultural-buildings-to-dwellinghouses/made

TRADA Technology (2012) *Future Opportunities for British Timber*. Bucks.: TRADA

UK Passive House organisation http://www.passivhaustrust.org.uk/what_is_passivhaus.php

Wellbeing of Future Generations (Wales) Act (2015) https://goo.gl/sQTRfv

WG (2005) *Development Quality requirements* (online) https://gov.wales/topics/housing-and-regeneration/publications/devqualityrequire/?lang=en

Zero Carbon Hub (2014) *Closing the Gap - between Design and Performance* (report), https://goo.gl/gc9DLo