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A Review of the Context of Low-Carbon Construction in Wales and an Introduction to a Research Project: a Technical Design Guide for Welsh Zero-Carbon Housing

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Abstract.
This paper introduces a research project investigating the design and construction of zero carbon housing in Wales, which will inform housing projects constructed through a development partnership Cardiff Council and a construction firm. The partnership intends to construct 1500 new homes over a ten-year period that commenced in 2016. The research is being undertaken to provide a basis upon which to reconsider the construction strategy of developments undertaken by the partnership, and to evaluate ways in which their carbon impact may be reduced. It will have further reaching impacts across Wales by describing a route to a vernacular of zero-carbon construction.

The project aims to produce implementable guidance for a model for sustainable, affordable housing in Wales with reference to the current and future housing stock. The threefold purpose of the research is to model enhanced occupant comfort and wellbeing, low operational and whole-life emissions, and cradle-to-cradle design, as an exemplar for mitigating climate change in the Welsh construction industry. This paper introduces the project within the contexts of the world-wide backdrop of climate change; the existing relevant Welsh governmental policy; and the need for adaptive technology in the construction industry.

1 Introduction

This paper introduces a research project funded by the European Social Fund through the vehicle of Knowledge Economy Skills Scholarships 2 (KESS2) and the Welsh Government. The KESS2 operation aims to support businesses and higher education establishments to carry out collaborative research projects which have a beneficial impact on one of four key areas, of which this project fits with Low Carbon, Energy & Environment. The project's core aims are: to review the existing methods of construction of affordable housing in Wales; to analyse at least one case study in terms of its strengths and weaknesses with regards to delivering low-carbon and low-energy living; and to present a series of strategies to deliver zero-carbon living within the remit of affordable housing as part of the construction projects constructed through the partnership between Cardiff Council and Wates Residential in Wales. Affordable housing in Wales for the purposes of Planning is defined as "housing where there are secure mechanisms in place

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to ensure that it is accessible to those who cannot afford market housing, both on first occupation and for subsequent occupiers"[1].

The 1500 Phase 1 dwellings to be delivered by the Cardiff Living partnership will be 40% affordable and 60% for private sale on the open market and will be delivered by 2027 [2]. The housing currently being delivered through the partnership is designed to perform 17% better than what is required by the Welsh Building Regulations [3].

The current construction strategy of the Phase 1 dwellings is traditional load-bearing masonry, with its high thermal mass - helping to prevent unacceptable summer overheating - being a key driver in its selection. They are designed with a fabric-first approach which limits operational energy demand. The traditional method of construction employed however contains high levels of embodied carbon by virtue of materials used such as cement, and by the high temperature required to manufacture materials such as concrete block and brick. Indeed, its construction strategy has been acknowledged as having key limitations including a 'large carbon footprint due to cementitious products and 'wet' construction' [4]. The research project therefore seeks to present to the Cardiff Living Partnership a design guide which has the potential when implemented to allow the Partnership's developments to be classed as whole-life zero-carbon, while maintaining buildability and appropriate cost.

2 Current Industry Context and Background

2.1 Urgency

An upward trend in global temperatures is now being recognised across the globe, as tangible consequences of climate change materialise in the form of acute natural disasters, weather events and ecological disasters of increasing frequency and magnitude [5]. The risk to our global ecosystem will remain high if changes are not made to our rate of consumption of natural resources. When the construction, operation and maintenance of the built environment account for nearly half of emissions in the UK [18,19] & energy use in housing 20% [8], developing a resilient, low-impact approach to construction and habitation is therefore paramount to improving our long-term prognosis.

This urgency is reflected in the current legislation; the Climate Change Act (UK) has increased UK-wide targets for a reduction in emissions above the 1990 baseline from 80% to 100% by 2050. The UK's Committee on Climate Change has recommended for Wales a lesser reduction of 95% due to Wales' high concentration of hard-to-reduce emissions such as agricultural emissions and low capacity for CO_2 storage [9]. However despite the challenges [10] the Welsh Government's intention is for this to increase to at least 95% if not 100%, in line with the rest of the UK [22, 23].

2.2 UK context

Against this backdrop, in England, Part L (Conservation of fuel and power) and Part F (Ventilation) of the Building Regulations are going through a consultation process, with new standards due to come into effect later this year. The consultation and associated research acknowledges the issue of overheating in new build homes and addresses the need for improved ventilation guidance. With 1.5m new homes to be built across the

UK in the next couple of years, a 5% increase on the total number of existing homes [8], these documents will have a large impact. However there are some within the construction industry who do not think the proposed changes go far enough to support the (legally required) route to a carbon-neutral economy by 2050 [13] and may actually signal a step backwards [14].

The Welsh Building Regulations (divaricated from the English) are also undergoing consultation. The Welsh consultation however is driving for reduction options to the Target Emission Rate for residential buildings over and above those of England's consultation and includes a lower set of U-Values to meet; the Welsh Draft Approved Document L states that "buildings which meet the standards set out in this Approved Document will meet the definition of nearly zero-energy buildings"[15].

2.3 National policy

The UK Committee on Climate Change acknowledges that without the introduction of 'clear, stable and well-designed' policy, targets cannot currently be met [9]; the Welsh Government has a threefold plan for how targets can be met in the building sector: through 'energy efficiency measures; low carbon heating measures; and behavioural change measures to the way we run buildings' [10].

The Welsh Government's Prosperity for All: A Low Carbon Wales Plan (2019), (extending from the Wellbeing of Future Generations Act (WFGA) (2015) and the Environment (Wales) Act (2016)), marks progress made in available guidance for the Welsh Government's roadmap for the decarbonisation of Wales [16]. The Plan will have an impact on all new housing from 2020 [16]. This extends to legislating that all new housing submitted for planning permission from 2020 will have to achieve nearly zero carbon or nearly zero energy use [16]; with a building's design life being at least 50 years, all new-build housing will be in use at the point of carbon-neutrality in 2050.

In terms of energy, the Welsh Government has a current non-statutory target for increasing total Welsh renewable energy supply to 70% of the total demand by 2030 [17]. Against this backdrop, 78% of energy generated in Wales in 2017 came from non-renewable sources [17]. A think-tank, the Institute for Welsh Affairs have since released a roadmap outlining a possible route to a 100% renewable Wales by 2035, of which a main driver is reducing energy demand alongside backing renewables [18]. It also recommends home-grown timber construction as a preferred strategy for new housing. While 2.8% of emissions in Wales are attributable to the manufacturing and construction industry (behind iron & steel and petroleum only), and 7.5% to residential buildings [18, 20], there is a need to improve carbon efficiency during construction but also to work to reduce overall carbon emissions being generated in new-build housing.

2.4 The zero-carbon dwelling

The UK Green Building Council defines a net zero whole life carbon building as "when the amount of carbon emissions associated with a building's embodied and operational impacts over the life of the building, including its disposal, are zero or negative."[19]. If we are to achieve the 95% emissions reduction in Wales by 2050, we must by then have developed the capability of building such whole life net zero carbon buildings; the 5% allowance is to account for hard-to-reduce emissions elsewhere.

There are a number of factors influencing the sustainability of a given domestic building. Following experimental projects in the recent past in the UK, the generally accepted core principles of low-carbon construction include: airtightness, insulation and heat recovery [20]. These all correspond to the need to reduce energy consumption in dwellings, which is a key area in which to concentrate efforts [21].. However, as energy demand in new-build housing decreases, so does the proportion of operational carbon emissions compared to whole-life carbon emissions. Reducing the emissions of both the operational and embodied carbon to zero, calculated over the lifecycle from pre-construction to post-demolition of a building, forms the basis for the design of a truly zero-carbon dwelling [20][22].

There are also qualitative features to consider when designing a good dwelling, such as toxicity of materials, indoor air quality, or designing for the wellbeing of inhabitants [19][23], which do not directly contribute to carbon reductions. Despite this there are often intersections with low-carbon design; for instance light, bright spaces which improve spatial quality and human comfort also reduce electrical lighting demand [24]. This project does not seek to dismiss such benefits.

3 Methodology

This research project investigates the potential reduction in embodied and operational carbon in affordable housing developments in Cardiff by focusing on resource choice (material & energy sources), resource integration (construction detailing, heating and ventilation & the performance gap) and resource management (whole-life carbon reduction and end-user behaviour). It is hypothesised that this can be achieved partly through the implementation of a fabric-first approach, cradle-to-cradle thinking [25] and through emphasising occupant wellbeing as a method of incentivising streamlined building services management. The project will examine the methods of constructing net zero whole life carbon housing in south Wales, through the following approaches:

3.1 Stage 1: existing dwellings analysis

The project will consider the different types of energy generation available and how they integrate with building design. The project does not seek to optimise or otherwise concentrate on energy as a main driver as the focus of the project is on building fabric and efficiencies. The project will evaluate energy usage and conservation and will consider how onsite energy generation can contribute to the decarbonisation of housing.

In order to do so, post-occupancy evaluation (POE) shall be deployed within a cross-section of the Phase 1 dwellings. Housing shall be evaluated through interviews and ongoing monitoring of interior conditions and measurement of energy usage to ascertain a baseline of performance, as well as providing data on occupant behaviour in relation to building performance. The ‘performance gap’ will be described through design information and as-built quantitative and qualitative data to build a picture of performance of the construction methods employed. This research will analyse how and if indeed the units perform to the projected 17% improvement above building regulations, and will create a benchmark for the second stage of the project.

3.2 Stage 2: evaluation of data and lifecycle analysis of proposed construction strategies

The operational carbon emissions of a dwelling can be reduced to zero or near zero following upgrades to the building envelope, and the provision of renewable energy sources to meet the unregulated energy demand. This can be categorised as truly zero operational carbon when energy storage is incorporated to allow flexibility of demand on the grid [26]. There is however an optimal balance to be found between the carbon cost of materials, and total operational carbon emissions. From the sectors contributing to the total embodied carbon of a dwelling [of a similar scale to the Cardiff Living dwellings], materials are by far the largest contributor at 80%, followed by replacements and maintenance (14%) and transport (5%) [22].

As well as zero operational carbon, in order to achieve a fully carbon-neutral dwelling emissions from the construction, maintenance and disassembly phases must reach zero [7]. This lends itself to 'cradle-to-cradle' thinking: an extension of lifecycle assessment, where not only is the overall impact of a given material or component assessed, but its compatibility, adaptability and robustness are also considered such that it is able to be repurposed at the end of the building's design life. Materials are able to be 'stored' during their life in one building before being disassembled and re-used in another or recycled - as their disposal 'costs' carbon emissions. As such, material choice and detailing offers an opportunity to greatly reduce embodied carbon.

Data analysis will identify possible interventions which may help to close the 'performance gap' during construction. The gathered information will be scrutinised alongside construction details and embodied and operational carbon analysis. This will inform the next stages of the project.

3.3 Stage 3: Proposal of zero-carbon design guide and evaluation of implementation within Cardiff Living dwellings

There is a substantial body of literature to support the carbon benefits of a paradigmatic shift away from load-bearing masonry as a perennially disseminated construction method and towards timber framing paired with off-site manufacture as a means of reducing the embodied carbon inherent in newly constructed dwellings [27]. This can be demonstrated both within and outside of Wales [28].

The Committee on Climate Change make extensive reference to wood in construction as providing a carbon-positive intervention to the industry [8]. Consideration of materials can also address the 5% contribution of transport mentioned above by supporting choice of locally sourced and manufactured materials. Material value can be created through design, for example 'plug-and-play' components such as prefabricated service cores combining mechanical and electrical systems with offsite solutions, for which timber is a well-matched material [9, 42]. Whilst the traditional construction methods of the Phase 1 dwellings help to mitigate potential overheating through high thermal mass, they do little to reduce carbon emissions. It is proposed that offsite manufacture paired with modern methods of construction can provide a way to increase the rate of new-build dwellings constructed while simultaneously improving their performance in terms of airtightness and fabric efficiencies, as well as a range of other economic and operational benefits [30]. This project therefore presents the challenge of

defining a construction strategy which overcomes the problems of traditional masonry construction through timber offsite manufacturing processes [9,41], while maintaining relevant construction skills [28], closing the performance gap [31], finding solutions to building control and insurance obstacles related to fire safety, and providing comfortable internal environments without unacceptable overheating.

The final stage of the project is the production of a technical design guide. Construction methods and details will be proposed which seek to reduce operational and embodied carbon within the constraints of acceptable comfort standards, whilst significantly reducing energy bills and improving occupant wellbeing. Working with the delivery partnership, the design guide will be introduced and subsequent buildings will be evaluated as per Stage 1. This will produce directly comparable data and will provide the opportunity for further analysis of construction strategies, occupant behaviour and the 'performance gap'.

3.4 Implications of COVID-19

For Stage 1 as described above, the researcher had originally intended to conduct interviews within each respondent's residence, to allow observational data - a 'walkthrough' [32] - to be taken in tandem with the verbal responses. Due to the restrictions imposed as a result of the global pandemic of COVID-19 however, it has been necessary to redesign this element of the POE such that online questionnaires are the key form of this type of data collection. This does offer certain advantages such as allowing more descriptive questions and a larger sample size than previously envisaged due to lesser time demands. Then, following the first stage of data collection and for a 'deeper' POE, further interviews around certain points will be conducted online through video conferencing software, with selected walkthroughs conducted following lifting of social distancing restrictions.

4 Conclusions

In this paper the authors present the drivers for research that aims to address a worldwide need for carbon reduction in the construction of housing, to allow a transition to a zero-carbon economy. The research aims to explore several themes and accepted approaches to reduction in both operational and embodied carbon. The paper has set out the policy background around which the research is centred and introduced the main aims and projected outcomes for the research. Is it intended that the research will play a part in the decarbonisation of the new housing stock being built in and around Cardiff for both social housing and private sale and rent.

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