CODE FOR SUSTAINABLE HOMES: OPPORTUNITIES OR THREATS FOR OFFSITE MANUFACTURING AND MASS-CUSTOMIZATION?

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Abstract:
This study intends to, firstly, discuss current status of zero carbon homes in the UK, and secondly, to investigate the feasibility of using offsite construction methods to deliver mass customised zero carbon homes. The study concludes that mass customised offsite housing could be an answer to overcome the current barriers to achieve zero carbon homes in the UK; however, more work is required to increase the confidence of stakeholders including clients, designers, and housebuilders in offsite manufacturing in order to increase the share of such methods in the construction industry.

1 Introduction

The UK needs around 233,000 housing units per annum during the next two decades [1]. This is while the current economic conditions have considerably affected the housing outputs during the recent years. Housing supply in 2010 sunk to 102,730 units, its lowest rate since 1924 [2], and only 146,000 units were added to housing stock in 2011 which is 43% less than 2008 [3].
Housing industry is one of the major sectors, which should contribute [4] towards the UK Government's long-term objectives to reduce carbon emissions by 80% by 2050 [5,6]. Domestic sector stands for around 29% of all the CO_2 emissions of the UK 66% of which is related to space heating, 17% to hot water, 15% to lighting and appliances, and 3% to cooking [7]. The UK government has announced its ambition to make new homes carbon neutral by 2016 [8,9,10]. This should be achieved through gradual amendments in building regulations based on the Code for Sustainable Homes (CSH) standards [11,12].
Energy efficiency standards have been included in the UK's Building Regulations since 1965 [11]; however, it was not until 2007 when CSH was introduced for achieving zero carbon homes [13]. According to CSH, houses are classified under six levels where Code Level 6 is the most sustainable level and achieves zero carbon emission [14]. The energy saving/improvement figures over the Building Regulations, Approved Document L (2006) for Code Level 1 to Code Level 6 have been estimated as 10%, 18%, 25%, 44%, 100%, and finally, zero carbon for Code Level 6 [15,16,17]. Code Level 3 is currently implemented through the building regulations and Code Level 4 will come in force through the building regulation amendments in 2013, before the 2016's regulations when zero carbon homes become mandatory (Table 1) [10,12,18].

Year	2010	2013	2016
Energy/Carbon improvements over Building Regulations Part L (2006)	25%	44%	Zero Carbon
Code For Sustainable Homes Level	Code Level 3	Code Level 4	Code Level 6

Table 1: Gradual improvements to building regulations based on CSH standards. Source of Table: [18]

The key drivers for the delivery of zero carbon homes are the legislations and regulations [19]. Limited knowledge and skills [19], and considerable extra over costs [16,18,20] are also the major barriers towards achieving zero carbon homes in the UK. It has been suggested that offsite methods of construction can help to achieve zero carbon homes [18] thanks to their higher quality [21] and fixed costs [18] compared to traditional methods of construction. Yet, mistakes made in the 20th century, which led to low quality dull offsite/prefabricated houses, and, consequently, bad public attitudes towards such methods are major barrios towards broader application of offsite methods of construction in the UK [22]. Mass-customisation seems to be a decent strategy to increase the share of offsite construction in the UK housing industry while avoiding the mistakes of previous decades.

This study intends to, firstly, discuss current status of zero carbon homes in the UK, and secondly, to investigate the feasibility of using offsite construction methods to deliver mass-customised zero carbon homes.

2 Zero carbon home

According to the Department for Communities and Local Government (DCLG) [18] a house could be considered as zero carbon if it genuinely produce a net annual zero carbon for the consumed energy for heating, cooling, washing, cooking, lighting, ventilation, hot water and electric equipment. This house could be described as Code Level 6 in the Code for Sustainable Homes [9]. Three requirements must be met for a home to be considered as a zero carbon home: [19,20,23]

1- Complying with the Fabric Energy Efficiency Standard (FEES) in terms of U-values, airtightness, etc.
2- Complying with the established Carbon Compliance limits (Table 2), established for zero carbon homes (after considering heating, cooling lighting and ventilation requirements); and
3- Reducing the remaining carbon emissions to zero

The third requirement can be met by intentional over-performance of the first and second requirements (by using, for example, photovoltaic panels, solar hot water, etc.) or can be achieved by investing in Allowable Solutions [20,23].

CSH was originally very ambitious requiring all regulated (heating, cooling, hot water, ventilation, auxiliary services and lighting) and unregulated energies (home appliances) to be zero carbon [10]. The "Allowable Solutions" was proposed in 2008 to provide some flexibility due to the difficulties (e.g. high costs, and feasibility issues on many sites) of delivering zero carbon homes on the basis of entirely "on-site" strategies [20]. The idea is that developers could pay to an Allowable Solution, which could be a small, medium or large offsite carbon saving project, to offset the remaining on-site carbon [20].

Building type	Fabric Energy Efficiency Standard (FEES)*	Carbon Compliance**
Detached house	46 KWh/m2/year	10 KgCO2/m2/year
Semi-detached house	46 KWh/m2/year	11 KgCO2/m2/year
End of terrace house	46 KWh/m2/year	11 KgCO2/m2/year
Mid terrace house	39 KWh/m2/year	11 KgCO2/m2/year
Apartment house	39 KWh/m2/year	14 KgCO2/m2/year

Table 2: Fabric Energy Efficiency and Carbon Compliance requirements set by CSH standards
Source of table: [20]

* FEES are the proposed maximum space heating and cooling energy demand for Code Level 6: Zero Carbon Homes.
** Carbon Compliance is the maximum permitted CO2 emissions from heating, cooling, hot water, lighting and ventilation.

2.1 Costs of delivering zero carbon homes

Achieving such high standards is not only difficult but is also expensive [16,18, 20]. Dwellings built based on Code Level 6 in 2016 could be up to 50% more expensive compared to the 2010 regulations. According to the Department for Communities and Local Government the total costs for achieving zero carbon homes is around £34 billion with an economic return of around up to £22 billion [17]. It has been estimated that Code Level 3 and Level 4 households can, respectively, save around £25-105 and £25-146 per annum. Code level 6 households may save up to £359 per annum based on the entirely onsite solutions [18]. This is while another study by DCLG in 2011 indicates that the extra cost ranges for three-bed semi-detached house at Code Level 3 were between £907–£1.588, £4.295–£5.361 for Code Level 4, £16,407–£29.326 for Code Level 5, and £31.127–£36,191 for Code Level 6 [16].

As shown in Figure 1, a major portion of costs for achieving zero carbon homes is related to energy efficiency, which is achieved through fabric improvements (insulation, airtightness). For example up to 79% of the "extra over costs" for a semi-detached three bed house is related to improvements on the energy efficiency while it accounts only for around 36% of the weight for the allocated points towards zero carbon homes [16].

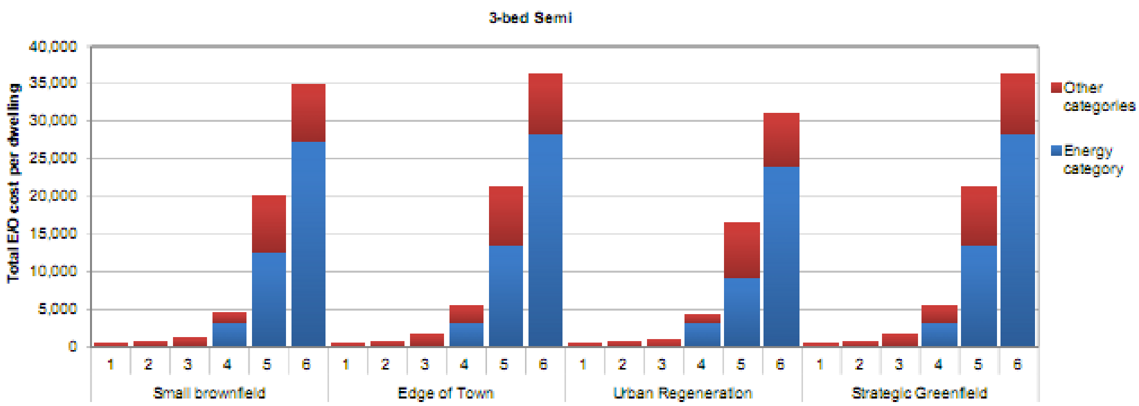

Figure 1: Extra over costs of 3-bed semidetached houses for different CSH levels from baseline Part L 2010 Source: [16]

2.2 Examples

Building Research Establishment (BRE) has established a permanent exhibition since 2005 in Watford, near London, known as BRE Innovation Park with the purpose of introducing Modern Methods of Construction, zero carbon homes and other innovative technologies [24]. The following are some examples of houses built in the BRE Innovation Park. Kingspan Lighthouse is the first home certified to Code Level 6 in the UK and Barratt Green House is the first zero carbon home built by a major UK housebuilder. The BRE Innovation Park not only provide builders with an opportunity to test and showcase their construction technologies and capabilities, but also is a great opportunity for designers, experts, and the public to see the innovations and emerging technologies and approached towards achieving a sustainable construction industry [24].

2.2.1 Kingspan Lighthouse

Kingspan Lighthouse was constructed in 2007 in the BRE innovation Park [24]. Kingspan Offsite has constructed its innovative 93 m², two and a half storey, two-bedroom Lighthouse (Figure 2) that is environmentally friendly and is designed according to the Government's CSH Level 6 to which all new UK houses should be designed and built by year 2016. The annual heating cost for the house (including water and space) is about £30, which means around 94% saving on fuel costs. The energy bills of a similar house with the same size and shape built based on the 2006 Building Regulations would cost around £500 [25].

Kingspan's TEK Building System, which is an offsite SIP (Structural Insulated Panel) system, has been used in the Lighthouse. Heat-losses through the building envelop, compared to a standard house, have decreased to around one third thanks to the very low U-value of the walls, roof and floor (0.11 W/m^{2}K) along with the airtightness of less than 1m^3/hr./m^2@50pa. Triple glazed windows (0.7 W/m^{2}K), low energy lighting, photovoltaic (4.7KW, 46m^2), wood pellet boiler (10 KW), rainwater harvesting, and the 88% heat recovery mechanical ventilation, in addition to A++ rated white goods [25] make the Kingspan's Lighthouse considerably energy efficient.

Moreover, proper use of thermal mass, passive ventilation, and solar shading helps to reduce energy consumption as well as maintain the indoor air quality. The rather low average daylight factor of 1.5 to 2% is however an area where improvements could have been made to make the Lighthouse even more environmentally friendly. Having been the first house certified to Code Level 6 standards, Kingspan's Lighthouse was a proper example for the UK's housebuilders and manufacturers during its rather short life from 2007 to 2012. It was demolished adopting a sustainable "zero-waste-to-landfill" approach last year [24].

Figure 2: Kingspan Lighthouse
Source: Authors

2.2.2 Barratt Green House

The Barratt Green House (Figure 3) is a three-storey, three-bedroom family home built to Code Level 6 Standards. Barratt Green House was constructed in 2008 in the BRE innovation Park [24]. It is the first home built by a major UK housebuilder, which meets the requirements to achieve zero carbon emission [24,26]. The Barratt house is constructed from wall with aircrete masonry blocks with thin-joint mortar, concrete floor slabs, Structurally Insulated Panels (SIP) roof and low U-value triple glazing [26].

Similar to the Kingspan's Lighthouse, Barratt Green House can achieve very low energy bills thanks to its high levels of insulations (180mm= 0.11W/m^{2}K), airtightness (1m3/hr/m2@50pa) [27], use of PV panels, rainwater harvesting, solar shades, heat recover mechanical ventilation, and highly efficient appliances [26]. Application of triple glazed windows with a low U-value of 0.68W/m^{2}K [27] has also helped to achieve a good glazing to floor area ratio of 25% [26] providing sufficient natural lighting while maintaining low heat-losses through the window.

Figure 3: Barratt Green House
Source: Authors

3 UK Housing and Offsite construction methods

Offsite construction is also known as prefabrication, system building, modular construction, system building, off-site manufacturing/ assembly/ production/ fabrication, and industrialised construction [28,29,30]. Offsite construction in 2009, as a whole, accounted for £2-3 Billion or around 2% of the UK construction industry [31].

Due to many reasons offsite construction has not been very successful in the UK construction industry [22]. UK saw an extensive use of prefabricated methods during the 20th century to answer the massive housing demands caused by the World Wars. During the 20th century about one million prefabricated homes were built [32] which led to negative public attitude toward prefabrication due to the low quality of design [33], poor materials and building skills [34]. The 1960s was the era of high-rise flats applying prefabricated building methods. At the same time, arguments against such types of buildings and methods of construction were becoming more evident [32,33,35,36,37]. Extreme use of prefabricated methods along with the uniformity and dullness of prefabricated houses gave rise to the arguments to replace these methods with alternatives to allow for more diversity, British identity, and personalisation [38,39]. Industrialisation of the construction industry was criticised by the society because quantity was valued much more than quality. In many cases designers failed to consider technical matters in conjunction with aesthetics while local authorities were criticised for losing their tenants' identity which caused several social problems such as depression, vandalism and other crimes [40].

The arguments on the necessity to increase offsite methods of construction has risen again during the recent years due to the needs for improved quality and providing affordable and sustainable houses in the UK. Supporters of offsite methods claim several advantages for these methods such as: improved speed; improved quality; improved health and safety; improved control conditions;

addressing skilled labour shortage; not weather dependent; minimized waste & energy consumption; enhanced value for money; cost predictability [34,41,42,43,44,45,46,47].

One of the major barriers towards broader application of these methods in the UK is their extra immediate costs [47,48,49] compared to traditional methods of construction. This is while traditional methods and practices have increasingly become less productive while their costs have increased significantly [28]. Moreover, successful examples, such as DFM 60K house competition in 2005, prove that offsite methods can be used to build affordable, high quality, sustainable houses [50,51]. Offsite methods have some other financial benefits, such as earlier rent and shorter borrowing periods, thanks to their less onsite construction periods compared to traditional methods [52]. However, given the current economic conditions and housing demand, housebuilders have no interest in faster construction period or in the improved quality offered by these methods. Buyers also seem to be more interested in the price and location of the properties than in the quality of houses. Therefore, developers are more likely to stick with the minimum requirements set by the building regulations than building high quality houses with less profit [47]. The main driver for using offsite methods of construction, therefore, seems to be the mandatory thermal and quality requirements set by the Building Regulation Part L [47].

4 Discussion

Although zero carbon homes can be achieved by traditional methods of construction [23], considering uncertainties in the quality and construction period of traditional methods [53,54], it is becoming more and more difficult and expensive to meet the requirements using traditional methods of construction [47]. Therefore, sooner or later, there will be a greater demand for the offsite products bringing the output/supply capacity under more pressure. According to Housing Forum, offsite-manufacturing (OSM) output in 2004 has been around 70% with expected increase to 80% in 2006 [55]. However, like many other industries, OSM is obviously suffering from considerable reductions in the UK housing output meaning that the production capacity is unlikely to be an issue in the short and mid-term. Given the current economic and housing conditions of the UK, it seems very unlikely that there would be a significant increase in demand for offsite products before 2016 when Code Level 6 becomes mandatory.

There are other issues, which should be addressed for successful delivery of zero carbon homes in the UK. Lack of enough knowledge and skills in the construction industry is considered as one of the major barriers towards delivering zero carbon homes [19]. Meanwhile, UK builders seem to have no objections against the increased use of offsite methods; however, they are concerned about whether offsite manufacturers can deliver products that match their specific needs and requirements [47]. Thus, offsite manufacturers should demonstrate as to how their products can address the current concerns on the knowhow, design, and delivery of zero carbon homes to increase the confidence of the industry in offsite methods.

Despite supports for offsite methods on delivering zero carbon homes, the general belief is that prefabricated methods may limit design flexibility and customisation [54]. This issue should be addressed by providing buyers, builders, and designers with more design flexibility without imposing extra costs. In fact, cost is the key factor for increasing the share of offsite methods and achieving mass-customisation (MC) [56]. Yet maximum standardisation is critical in achieving economies of scale. This should be achieved by generalising the design features, such as structural elements and dimensions, to be able to reuse the knowledge, processes and equipment throughout the production process. This has, to some extent, been applied by some builders who offer customisation on houses at late stages of construction through different elements and accessories such as external claddings and interior designs and fittings [31,57]. However, the ideal situation for designers and buyers would be to integrate customisation early in the design stages to provide buyers/designers with more flexibility.

Once, reducing costs of construction by removing costly and highly labour intensive tasks, such as bricklaying, was the objective of offsite methods of construction [36]; whereas MC is today one of the key concepts. When considering MC, suppliers should adapt quickly to the clients' specific requirements without scarifying the efficiency of mass production [58]. Applying computer-aided design and manufacturing (CAD/CAM) systems have created an opportunity to have significant variety in the products without affecting the construction feasibility [56,59].

However, there are always some limits to the extents to which customisation can be achieved [60]. The fundamental question, therefore, remains the same that as to what degree standardisation should be considered to avoid monotony and to make the products aesthetically acceptable even with the price of rather less efficiency in terms of costs and economies of scale.

Unlike the UK medium and large housebuilders, which may provide up to 30 plan options [57] with minimum or no options for customisation [61,62], Japanese MC housing providers, for example, may provide up to 300 standard plan and elevation designs [57], combined with internal specifications, finishes, and fit outs giving a countless customised options to the customers to choose from. The choices are however regulated by the economies of scale for the external claddings, planning regulations, size and orientation of the plot, predefined approved set of fittings and fixtures, and last but not least the income of the clients [57]. Similar approaches may be adapted by the UK housebuilders to maximise benefiting from offsite construction without increasing the costs and decreasing the aesthetic values of design.

5 Conclusion

Despite several efforts, offsite methods have never been able to take the place of traditional construction methods in the UK [22]. The history of the UK housing has shown that traditional systems are here to stay regardless of regulations and standards. Traditional methods have always improved themselves by becoming more efficient and cost effective competing with offsite methods of construction. Therefore, although CSH standards and building regulations will probably make the offsite methods more desirable, it would be unrealistic to assume that CSH would significantly decrease the share of traditional methods replacing them with offsite methods of construction.

Moreover, considering the current higher prices of offsite construction methods, there should be doubts about the arguments, which suggest that building to zero carbon standards would be cheaper if offsite methods are used. In fact studies on similar claims about the prefabricated methods during the past century suggest that claimed reduced costs of prefabricated methods at the time had more to do with the efficient construction processes by well organised developers than being purely related to the methods of construction [36]. The majority of the available costing figures are based on the assumptions and comparison of rather different housing developments. Costs are greatly affected the volume, size and form, energy efficiency figures, construction methods and technologies, finishing standards, provided services, and infrastructure [63]; hence more research is required to compare the costs of traditional methods with the offsite methods of construction when building to zero carbon standards.

Considering the very high standards of zero carbon homes, higher quality and fewer deflects of the offsite methods (thanks to the factory quality controls) are probably stronger and more realistic arguments, which may encourage housebuilders to consider such methods. Offsite suppliers therefore should not only rely on the regulations drivers but also should seek for other incentives, such as reducing the overall costs and associated risks, to make offsite methods more attractive to the stakeholders including the clients, builders, and designers.

One of the major barriers towards broader application of offsite methods of construction is the negative public attitude towards such methods [59]. UK construction industry is still suffering from the bad memories of the 20th century when dull and boring prefabricated houses caused several social and economic problems [22]. Providing variety and personalisation through MC is a way out of this dilemma to rebuild the public confidence in these methods.

The UK offsite manufacturing is immature particularly in the mass customisation housing. Much work is required to understand the requirements of the UK housing market based on which offsite manufacturers and developers can adapt their products and services to match those requirements. Yet there are great opportunities for offsite methods to gradually increase their share in the UK construction industry. Mass customisation would be a crucial issue in the future; however, given the current situations, cost is the key factor in the success or failure of offsite methods of construction and mass customisation in the UK.

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