Design for Deconstruction in UK Timber Framed Dwellings

The identification of design for deconstruction sensitive details

SOPHIE CHISHOLM

1Aedas R&D, London, UK.

Initial research undertaken at Oxford Brookes University

ABSTRACT: This paper will introduce the necessity for incentivising a method to retain materials, and therefore their embodied energy, in the resource loop. It will investigate the contemporary legislative context and go on to outline the portfolio of analysis techniques utilised to identify DfD-sensitive details within a case study: Stewart Milne’s Sigma Home. The detail identified as having the highest sensitivity will be compared to a modified, DfD-enhanced version - both in terms of embodied carbon to establish the success of the exercise.

Keywords: timber, housing, deconstruction, embodied energy, embodied carbon, waste.

INTRODUCTION

Since the Industrial Revolution, mankind has been extracting natural resources at an unsustainable rate. It has been the substitution of resources for human labour that has yielded an increase in our productive capacities. However, this substitution has resulted in the deterioration of the living systems that not only absorb our waste but also provide our resource base [1]. Despite the negative effects of this process, environmental drivers alone have not been adequate incentives for a discernible change in behaviour. This has led to the implementation of legislation which sets out to achieve a 34% cut in emissions below 1990 levels by 2020 and at least 80% by 2050 in the UK. The UK Carbon Transition Plan aims to cut emissions from homes by 29% from 2008 levels by 2020 [2,3].

RECENT REFRAMING

The formation of the Coalition Government in the UK in 2010 led to a widespread overhaul of Government Policy based on their pledge to be the ‘greenest government yet,’ and their ‘Big Society’ manifesto [4]. The previous labour government had been working to a new homes target of 3 million new homes by 2020. The Big Society restructure has passed all planning and housing decisions down to the local level, and plans are being drawn up for the incentivisation of new developments. Although deficit demands and budget cuts have taken their toll, new housing development is likely to be of a similar order to previous targets [5]. With this in mind, it is more important than ever to find a way to retain the embodied energy and resources that are locked into these new homes. One of the weapons in the climate change mitigation artillery is design for deconstruction (DfD).

DfD is a method by which to preserve building components, retaining them in the resource stream for their future reuse. As a topic, reuse features in many Coalition documents: ‘2010 Strategy for Sustainable Growth’, [6] ‘National Security Strategy. A Strong Britain in an Age of Uncertainty,’ [7] as well as other recent Labour endeavours such as the Climate Change Act 2008 [8], elevating it from ‘Scrapheap Challenge’ status to a social and environmental responsibility.

UK WASTE

In 2008, England produced 165.1 million tonnes of waste across the domestic, industrial and commercial sector. The largest contributor was the construction, demolition and excavation sector, generating 49% of that figure and estimated to account for around 3% of all direct UK emissions [9]. The Government Review of Waste Policy in England 2011 adopts and outlines the waste hierarchy, previously absent from its parent document, which highlights prevention as the most effective way of dealing with waste. Waste prevention plays a large part of the Coalition’s plans to create a low carbon economy not least by generating employment opportunities in the transition from a disposal-centric sector towards one of reuse, recycling and recovery of waste [ibid].

TIMBER FRAME

Timber frame is the fastest growing method of construction in the UK. There are many drivers for this, the biggest being the huge environmental benefits of utilising this material. A typical 100 square metre timber framed dwelling saves approximately 4 tonnes of carbon dioxide, which is equivalent to the emissions produced by
driving 14,000 miles [10]. Despite the global deforestation problem, the forests of Europe are increasing by approximately 650,000 hectares per annum, leaving very little having to be sourced from elsewhere. Wood is also less energy intensive to process than many other building materials due to its innate workability. It also has a comparatively high strength-to-weight ratio, which reduces groundworks. Unlike concrete and steel, it has good thermal performance, minimising the problem of cold-bridging in a design. Wood also captures carbon as it grows, therefore the recycling and reuse of wood extends the carbon benefit of the material dramatically. In employing a culture of reuse, timber contained in the housing stock can act as an urban forest for harvesting [11,12].

There already exists a body of work produced by many DfD proponents globally, many of them in the US. A large amount of the DfD detailing and specification work carried out so far has focused on layers such as the external finish [11]. Since the structure of a building tends to have the longest lifespan and is often comprised of the largest members, an alternative approach was adopted for the research, and the timber structural elements of the case study were chosen for DfD analysis. An interview with the owner of a reclamation yard highlighted key points for consideration that are appropriate for DfD most notably; reclaimed materials do not come with structural guarantees or warranty which means that specimens that would be suitable for structural purposes are rarely utilised as they need to be signed off by a structural engineer. The second significant point is that, as a rule, smaller, softwood timber members have replaced larger, hardwood timber members; softwood being considered an inferior material [13]. In light of this, in the contemporary world, DfD emphasis must be attuned to modular, component deconstruction - i.e. of wall, floor and roof cassettes - as opposed to individual member deconstruction.

AIM

This paper aims to outline the portfolio of analysis techniques utilised to identify DfD-sensitive details within a case study: Stewart Milne’s Sigma Home. The detail identified as having the highest sensitivity will be compared to a modified, DfD enhanced version, in terms of both embodied carbon and cost.

LIMITATIONS OF RESEARCH

Elements highlighted in the case study as DfD-sensitive may not be directly transferable to another timber framed case study. However, the methods of analysis can be utilised in the same way. These analysis methods have used embodied CO₂ comparisons, there are not sufficient resources to gather this information for the case study. Instead, average embodied energy figures have been used as a point of comparison. This is not ideal, as embodied energy figures do not account for the carbon weighting of different fuels used in cradle-to-gate processes. The final limitation is within the cost analysis section. While realistic prices per m² and m³ were obtained, it was not possible to gain access to the contractors in order to establish realistic time and labour savings in the existing and proposed details. Since this is the area of DfD in which the largest cost savings are made, a true savings analysis was not possible.

LITERATURE REVIEW

A literature review was performed in order to establish historical precedent and to devise a set of key performance indicators for successful DfD. Design for deconstruction as a comprehensive subject is not a new concept within the built environment. The Vernacular is the archetype of design for adaptability (DfA), with the buildings having been developed in true synergy with their context [11,15]. Till [17] describes his overriding architectural theory of ‘Mess is the Law;’- a design will be dependent on many external factors such as people, circumstances, events and environment. He postulates that much of modern architecture however is shaped by the internal processes of the architect, eliminating its contingency. Vernacular architecture is not affected by such factors and is shaped only by the external environment, escaping the influence of ego [ibid]. Portable shelter is an area from which to draw DfD inspiration; exhibiting rapid construction and innate demountability [12]. The International Style displays DfD qualities; non decorative buildings constructed of pure materials and connected with bolts were fundamental to this movement [15]. The Acharacle Primary School, Argyll was designed by Gaia Architects using the Brettsapel technique, which is a glue-free method of massive timber construction, and the first of its kind in the UK. Solid timber softwood posts are laid side-by-side and are fixed together with 16mm hardwood dowels. When the building reaches the end of its service life, the dowels can be drilled out and the fabric reused [16]. Presently, the precedent DfD knowledge base is very diluted across many examples. The various strategies employed, such as functional articulation, bolt joints, pre-designed services and careful specification of materials, need to be amalgamated and refined. The widespread use of wet trades, particularly within the domestic sector, where they are utilised to ensure airtightness, makes DfD extremely difficult.
SIGMA HOME AN OVERVIEW
The Sigma Home is the result of collaboration between Stewart Milne Timber Systems and PRP Architects. It utilises a state of the art timber-frame technology for the UK. Based on a Victorian terraced house, the Sigma Home is the height of a three storey house and is set out on four split levels, maximising natural light [18]. It comprises of two semi-detached dwellings. Floor layouts are designed to be open-plan to reflect modern lifestyles. The lightweight timber floor, wall and roof cassettes are factory-fabricated and delivered to site floor-by-floor [19]. Flexibility of plan has been considered throughout the design. Floor plates are connected to a central core which includes the staircase, bathrooms and other highly-serviced areas. This eliminates the need for load-bearing walls [20].

ANALYSIS METHODS:

LAYERING

One of the major manifestos in DfD is on the lifespan of a building vs. the durability of the materials or products it is comprised of [21]. These discrepancies can be overcome with intelligent design that enables building fabric to be removed unadulterated. Stewart Brand developed a layering diagram that goes some way to explaining the solution, illustrating the independent layering of building elements to facilitate the maintenance, upgrade or removal for reuse of components [15]. The Sigma Home was been divided into layers, following the Stewart Brand theory for deconstruction. These layers, listed in order of relative life spans: most stable to most adaptable, (1. Structure, 2. Roof cladding, 3. Subassemblies, 4. Services, 5. Wall cladding). It is logical that the more permanent layers should be designed for larger element deconstruction and reuse, while the layers with shorter life spans should be designed for minimum waste during adaptation.

MANUFACTURING PROCESS
An analysis of the manufacturing process was undertaken to highlight any DfD issues and potential areas of improvement. Three key DfD obstacles were found. Firstly, factory fixings are predominantly nails and nail plates, both of which are difficult to remove and cause damage to the fabric. Secondly, each stage of the process is fixed in a sequential manner, each component being fixed to the one below. Lastly, due to the two-stage construction of the Sigma Home - factory fix and site-installation, the crossover between the two becomes important. Conventional drawings present difficulties when performing DfD analysis; the absence of material, dimensional and fixing information on most drawings results in confusion on site during construction and a lack of transparency when it comes to deconstruction. Presently, wall and floor cassettes are sent to site with no obvious instructions for the site installation of finishes. If a platform were to be provided on the cassettes from which to offer up the site installed components, fixings could be minimised and a strategy for disassembly reached.

COMPONENT DEPENDENCIES
Durmisevic [21] argues that the primary issue for deconstruction is the discrepancy between the durability of most materials and the durability of their functions. By graphing these two variables in a life cycle coordination matrix it is possible to identify deconstruction-sensitive elements and components. Since many materials and components outlive their service life, the next priority is the recovery of these materials. Dependencies between materials and components within buildings are often the reason for demolition or large scale renovation. These dependencies can be represented in graphical form. Figure 2 represents the Sigma Home dependency diagram.

Figure 1: Sigma Home Hierarchy Diagram
EMBODIED CARBON & DISASSEMBLY MATRICES

In 2006, Brad Guy performed an environmental impact study on three structural systems in order to analyse their comparative environmental impact and the lifespan of the materials. He set out criteria for prioritising for DfD,

- The quantity of material
- The environmental impact of a material
- The ease of recovery
- The value of material after recovery
- The lifespan of a material. [11]

He begins by analysing the structural systems in terms of percentage weight of material and then converts this into CO₂. This is a useful exercise as there may be a small amount of concrete or steel in a design, but their relatively high embodied energy and embodied CO₂ may skew the results and underline these components as the most environmentally expensive and therefore most necessary for attention. A disassembly matrix is then devised illustrating the recycling and salvage potential in terms of high and low value. This analysis adds another layer of transparency to the design.

By triangulating weight of material with ease of recovery and embodied CO₂ it is possible to determine priorities for DfD [ibid]. This exercise was carried out for the Sigma Home. Figure 3 illustrates the relative embodied energy figures per square metre of each component type, alongside the percentage embodied carbon each component is responsible for across the case study as a whole. The first bar highlights the party walls and the external walls while the second bar highlight the party walls and the mid floor cassettes as being of greatest significance in terms of embodied energy. This confirms the importance of both the mid floor cassettes and the external walls, reiterating their importance as emphasised within the process-driven discussion, while the party walls have not been identified in the previous analysis techniques.

Figure 2(overleaf): Sigma Home Dependency Diagram
DETAIL SELECTION AND DfD ISSUES

The layers of the Sigma Home are completely integrated, rendering it impossible to adapt or deconstruct. The Sigma Home can be split into layers, and again into key components in each layer. Ideally, a deconstruction plan would begin with the deconstruction of the roof cassette downwards. However, due to time limitations, this research has focused on the detail found to be most DfD-sensitive. This was chosen using a process driven method based on existing and current research by Stewart Milne, ease of upgrade (dependencies), quantity of material and embodied energy.

The design of the internal wall junctions with the external walls and floor make elemental deconstruction impossible. Component adaptation is hindered by the use of wet trades on these components. The external finishes are comprised of multiple layers of fabric, each nailed to the layer below and eventually onto the wall cassette. This prevents the simple adaptation or upgrade of the insulation or finish and causes severe damage to the wall cassettes below.

DfD issues for the selected detail (figure 4) are listed below:

1. A 38 x 140mm locating plate is fixed above the floor cassette in order to receive fixings from the external wall above. These connections are all made with nails and are located as shown in the diagram.

2. The underfloor heating system requires 38 x 50mm battens to be fixed with nails at 400c/c to the floor cassette decking. 22mm chipboard is subsequently glued and nailed above this to prevent squeaking.

3. A 38 x 140mm head binder is fixed to the external wall in order to provide a suitable point for fixing the floor cassette above. Various nail fixings are utilised, causing excessive damage to the timber members.

The solution for this detail is complex. As well as complying with the key parameters and performance benchmarks set out above, it must deal with split deconstruction requirements. The factory built floor and wall cassettes should be detailed for deconstruction while the site fitted finishes should be detailed for adaptation as these are likely to be replaced or upgraded many times during the service life of the building.
A series of 3 step-by-step modifications was devised, each building on the last, to eliminate one of the issues identified. Figure 5 illustrates modifications 1,2 &3.

1. The first modification made to the detail is to add 100mm of flexible batt insulation behind the edge binder in order to address the issue of cold bridging from the outside air. The head binder and locating plate have also been removed and an L-shaped joint created as part of the factory made floor and wall components. Once delivered, the components are bolted together. This joint renders the components suitable for reuse.

2. The installation of a floating floor construction removes the requirement for battens and therefore many damaging fixings. It also eliminates noise caused by friction between components. Electric mats are utilised in place of the conventional pipework. These mats can be sized to individual floor cassettes and individually connected to the manifold.

3. This illustrates a solution utilising a closed panel system, which removes the site installed service void and associated degradation in thermal performance. The services are predesigned and chased into the inner layer of plasterboard. Once connected to the floor cassettes, the floor and ceiling finishes are run up to butt against these. The floor cassette now arrives at site with a preinstalled airtightness membrane.

A detailed cost analysis was performed on a 1 square metre section of floor cassette and corresponding wall cassette sections for the existing detail and iteration 3. Iteration 3 was calculated to make a saving of £42.32 per section over the existing detail in terms of materials. Analysis also demonstrated that there are only 10 operations in iteration 3 compared to 16 in the existing detail, allowing the potential for more savings in labour cost.

CONCLUSION
This paper concludes that there is a raft of analysis techniques that can be employed in order to establish the details critical for DfD, a process which is most robust when the strategies are employed in parallel. It also concludes that it is possible for a DfD design to be more economically viable than conventional detailing and therefore points to knowledge and skills barriers as being more likely. In order to reduce waste and retain embodied carbon in the resource loop, it must be a consideration up-front at the design stage in order to maximise potential for design for deconstruction.

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