CL:AIRE

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subr:im bulletin

CL:AIRE's SUBR:IM bulletins present practical outcomes of research by the SUBR:IM consortium which have direct application to the brownfield and contaminated land communities. This bulletin considers the impact of design for deconstruction on the environment and how future generations can avoid problematic brownfield sites.

Avoiding Future Brownfield Sites through Design for Deconstruction and the Reuse of Building Components

1. INTRODUCTION

Is it possible to reduce the number of future brownfield sites by altering building design? And therefore, in doing so, is it possible to develop a built environment that aims to return land to its previous undeveloped state? At the core of the Design for Deconstruction (DfD) philosophy are both these objectives and many more. In recent years the acceptance of DfD has shifted from dismissal of the notion to the inclusion and demonstration of demountability on site. Demountable warehouses that yield reusable components are here (Barratt 2007), the next step is applying demountable construction to run-of-the-mill structures within the hearts of UK cities. This bulletin discusses how this may be achieved and the benefits that can be derived from designing buildings so that they can provide a legacy of components suitable for reuse for future generations whilst treading lightly on the ground.

Sustainability culture is here to stay (Brundtland 1987), part and parcel of which is the recycling of brownfield land and urban regeneration. Contaminated brownfield sites are frequently investigated to develop remedial technologies. However, brownfield sites without contamination are generally disregarded with little attention focused on the methods of construction that make up the urban environment. This bulletin highlights that reductions in environmental impact can be achieved by adopting construction methods and systems that could reduce the generation of un-contaminated problematic brownfield sites.

2. DESIGN FOR DECONSTRUCTION (DfD)

Design for deconstruction is an emerging design approach that promotes forethought into the end-of-life decommissioning process of a buildings life cycle. In particular the focus of DfD encourages and promotes the systematic disassembly of a building with the intention to reuse building components. The aims of DfD differ from that of recycling and material reclamation as these are orientated towards the recycling and reuse of components retrieved from traditionally constructed buildings coupled with traditional demolition activity (Fig. 1). An example of this is the BedZED development (Fig. 2) which was constructed with salvaged components from buildings that were not intentionally designed to facilitate the reuse of building components. In contrast to this, DfD develops a long-term vision of material and building component flow streams, whereby it is possible to predefine the end-of-life deconstruction sequence. By doing this it is possible to provide accurate inventories of the grade, specification, and quantity of materials suitable for reuse at the end of the first generation DfD building's life cycle. This is achieved by addressing key design and construction principles that hinder deconstruction and component reuse and are commonly used to construct today's built environment.

Figure 1. Traditional demolition, destructive and disharmonious to the aims of DfD.

Figure 2. BedZED, an example of material salvage/reclamation and reuse.

Adopting a DfD approach to new building design has the advantages of:
• Reducing the amount of material discarded to landfill.
• Increasing the amount of material suitable for reuse at the end of the buildings life cycle.
• Initiate the development of closed loop material flow streams within the built environment.
• Attain a higher echelon of waste management (Figs. 3 & 4); key to this is the progression from recycling to reuse, as defined by the waste hierarchy (Fig. 5).

Figure 3. On-site waste management. Masonry rubble visible in the foreground with recyclable steel sections in the background.

Figure 4. On-site waste concrete crushing plant used to downcycle concrete to secondary uses.

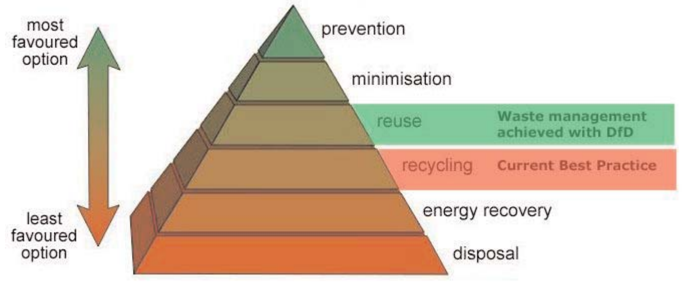

Fig 5. Waste hierarchy indicating current best practice and what can be achieved with DfD.

- Advance sustainable construction so that the built environment is an asset rather than a legacy of waste.
- Reduce long-term carbon emissions through reuse.
- Reduce the environmental impact of new developments.

Design for deconstruction as a building design approach is in its infancy and is has not yet been demonstrated on-site on a large scale. Furthermore there are few structures that have been constructed, deconstructed and the components reused. This project has investigated the feasibility of DfD based on a comparative study of three existing 'as built' buildings against redesigned versions of the same building that have been altered to assist in the deconstruction process.

3. CASE STUDY BUILDINGS

The three case study buildings were selected based on their ability to represent construction best practice and modern methods of construction within the commercial and educational sector. They represent typical construction methods that are widely used to construct the modern built environment within most UK cities and purport to deliver sustainable buildings by utilising advances in construction such as off-site manufacture and waste minimisation techniques.

The purpose of this study is to establish if "*the design of a building may be altered to maximise the yield of reusable components without adversely affecting the viability and practicality of the construction process.*" The methodology used to test this hypothesis is based upon comparative analysis of 'as built' existing building stock against hypothetical redesigned buildings that are suitable for deconstruction.

The study relied heavily on collaboration from the demolition industry in order to understand the demolition process for modern buildings. The requirement for this is borne from the lack of information available concerning demolition techniques and strategies. Furthermore, it was apparent that the demolition process would require amendments in light of deconstruction. That is to say a predefined and systematic deconstruction process was required in order to further evaluate the process of deconstruction that could be adapted by the demolition industry.

'As built' data was collected for the three case study buildings. Case study building 1 is a mixed use educational building with a floor area of 5600 m^2 spread over seven floors. It is constructed using hybrid pre-cast and cast *in situ* reinforced concrete. Case study building 2 (Fig. 6) is a four storey steel framed office structure with pre-cast hollow-core floor planks and a floor area of 1800 m^2. Case study building 3 has a floor area of 2800 m^2 spread over four floors and is a steel framed building with trapezoidal composite decks with *in situ* reinforced concrete.

Material inventories for the three case study structures were compiled and analysed using Life Cycle Analysis software that has the capacity to produce inventory environmental impact assessment.

For the purpose of this bulletin, case study building 2 will be used as an example from hereon in. The material quantities that constitute the building are shown in Table 1.

Figure 6. Case study building 2.

Table 1. Material quantities for case study building 2.

Material	Tonnes
Concrete inc. reinforcement	1400.2
Steel	626.2
Glass	108.6
Plasterboard	23.5
Insulation	1.9
Brick	92.3
Floor coverings (various)	22.5
Total	2275.5

In order to gauge the relative environmental impact of each component group for case study building 2, an inventory environmental impact was conducted. The component groups contribute to the inventory environmental impact in the following order:
- Structural Steel Frame
- Floor Slabs
- Sub-Structure
- Cladding
- Surface Finishes

The inventory environmental impact assessment is presented in Figure 7.

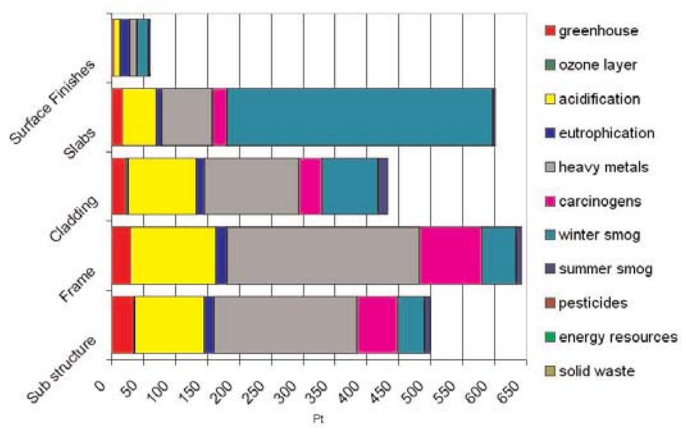

Figure 7. Inventory environmental impact assessment for case study building 2.

4. INVENTORY, LIFE CYCLE AND DISPOSAL ANALYSIS

In light of the inventory environmental impact assessment, the structural steel frame and the floor slabs became the priority category groups suitable for design for deconstruction. The selection of these component groups is a combination of factors. For example, although the sub-structure and cladding are also environmentally burdensome in relation to the frame and floor slabs, the likelihood of reuse is relatively small. In general terms cladding components, due

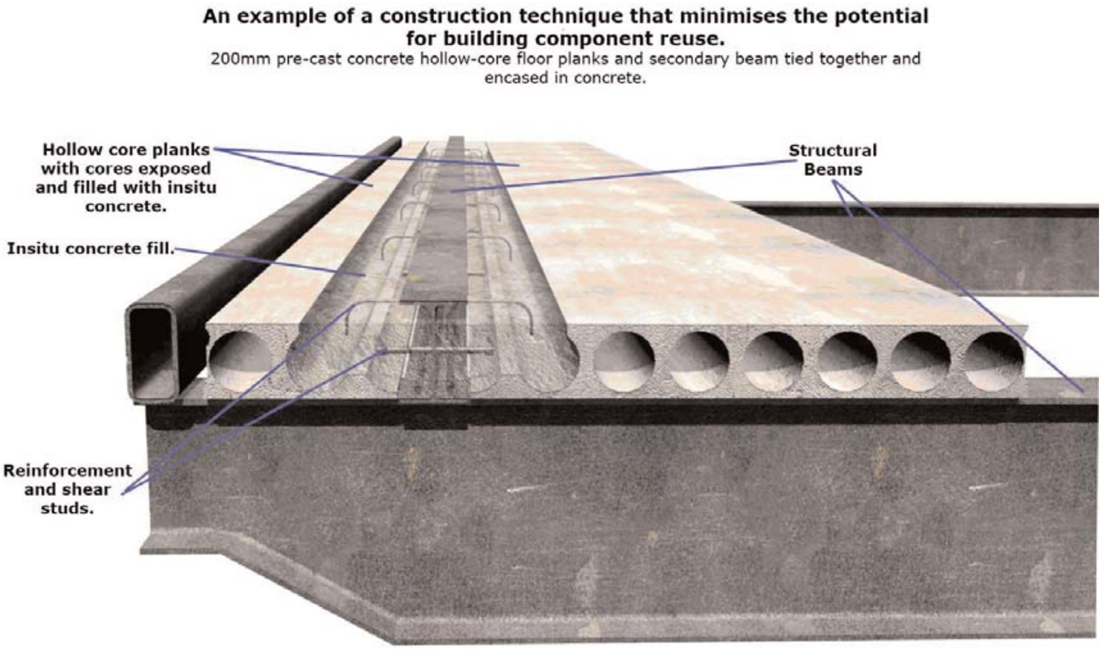

Figure 8. Construction method of case study building 2. Pre-cast floor planks irreversibly attached to steel beam.

to their operational conditions, are subject to weathering, ageing and deterioration over the life span of the building and are therefore in realistic terms unlikely to be specified for a second generation of use. Similarly, concrete substructures are likely to have evidence of degradation having been exposed to aggressive conditions below ground level. In such cases it is more than likely that these components will be downcycled and reused for secondary uses such as backfill, pile mats or if of sufficient quality, used as aggregate in the manufacture of new concrete.

In addition to the inventory environmental impact assessment, there was a need to further understand the methods of demolition that would be used to demolish the case study building. As the renewal of the built environment gathers pace, the construction methods have become leaner, in respect of material consumption and cost. The impact of these 'cutting' technologies is yet to be determined as there are not many examples of modern construction methods that have been demolished in large numbers. That is to say, methods of construction such as hollow core concrete floor planks stitched to steel beams in a manner that induces diaphragm action have not been demolished in large numbers. Therefore the knowledgebase for material arising from demolition activities of such structures is not readily available. To counter this and better prepare for the redesign process, representatives of the demolition industry were consulted to assess the case study buildings for waste arising from demolition activities and methods of demolition. More importantly, the consultation of the demolition industry served to provide an insight into obstructions that mitigate the likelihood of component reuse. In response to the demolition assessment of the floor slab and structural frame of the case study building, a demolition contractor commented, "*It is difficult to concentrate demolition activities on a single element because most of the construction methods used to construct buildings like the case study buildings are not aimed at reuse. The building elements usually interact with those surrounding it, so disturbing one of them results in damage to another (Fig. 8). A clear example of this is the floor slabs in question, how do you undo concrete? The steel beam and concrete act as one, meaning they will both come down as one.*" Further similar responses compounded the opinion that structural steel frames should be designed in a manner that allows the reuse of the steel sections without damage during deconstruction.

The components ideally suited to second generation reuse are those that can demonstrate little deterioration over the life span of the building. Furthermore they must be sufficiently robust so that they are capable of resisting damage during the deconstruction process (Addis 2007). It is suggested that structural steel components are ideally suited for use in second generation buildings because their individual life cycle is far longer than the building itself. In most cases, if adequately protected against corrosion, metal fatigue and the effects of fire, the properties of steel sections are unchanged regardless of age. Therefore, the focus of redesign activities to include design for deconstruction principles was aimed at facilitating the reuse of the structural steel frame and the floor slabs.

Figure 8 shows the interaction of the steel floor beams and the hollow-core floor planks. The planks are tied to one another to form a floor plate which is then irreversibly fixed to the top flange of the steel beam using welded studs. This is a typical example of irreversible component interactions that mitigate the likelihood of reuse. The effect of the irreversible construction methods on the disposal stage of the buildings life cycle are shown in Figure 9.

The disposal stage of a buildings life cycle presents the opportunity to offset or reclaim the inventory impact shown in Figure 7 through reuse, recycling and downcycling. The input materials used to construct the case study building have an impact of 2240 points which represents 100% of the constituent materials used to construct the case study building. At the end of the case study building's life cycle it is possible to offset 821 points worth of environmental impact if the waste material is sent to existing waste, recycling or downcycling streams, this represents 37% of the construction related environmental impact (Fig. 9).

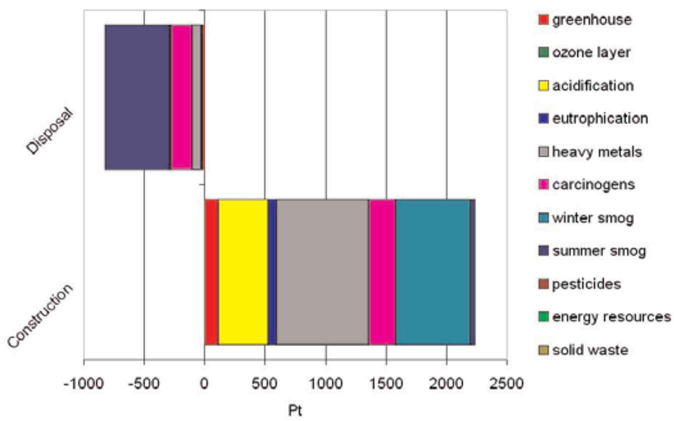

Figure 9. Construction and disposal inventory analysis for case study building 2.

The reduction of the end of life environmental impact relied upon the redesign of the interaction between the floor slabs and the steel frame. The redesign floor slab interaction was tested for its suitability for deconstruction by the demolition industry. The objective of this step was to validate the ability to counter the floor/beam interaction, and to establish the likelihood that the systematic deconstruction procedure was feasible and likely to be accepted by the demolition industry. An insight into the demolition contractor's perspective was summarised by one of the respondents who commented, "*The traditional method of constructing the case study building did not provide any opportunity for reversing the bond between the structural steel sections and the floor slab. The [revised deconstruction] solution provided for this case study building demonstrates a clear method and technique for separating the components. Obviously there are other issues to take into consideration such as obstructions to the connections.*" However, "*If the whole of the case study building is designed so that these obstructions (plasterboard/surface finishes and/or services) can be sacrificed or discarded there is a good chance the majority of the structural sections can be removed undamaged.*" In addition to the assessment of the deconstruction procedure, material waste streams were recalibrated to take into account the reuse of the steel sections.

The assessment data obtained from the demolition contractors was reintroduced into the life cycle model. The inventory environmental impact increased from 2240 points to 2351 points (5% increase) which can be attributed to the increased materials required to construct the demountable floor slabs and floor beams (Fig. 10).

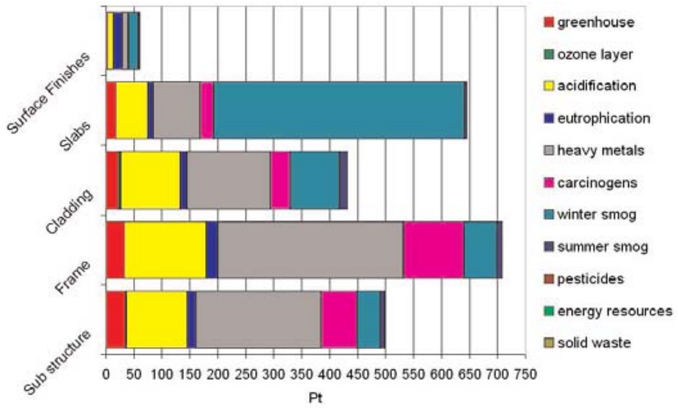

Figure 10. Inventory environmental impact assessment for redesigned case study building 2, incorporating design alterations to facilitate deconstruction.

Although the initial increase in material is relatively small, the end-of-life environmental gains are substantial. The redesigned case study structure enables the offset of 1202 points of environmental impact (Fig. 11), representing 51% of the inventory environmental load. In comparison to the traditional methods of construction, the design for deconstruction alternative provides the opportunity to reduce the whole life cycle impact of the case study building by 14%.

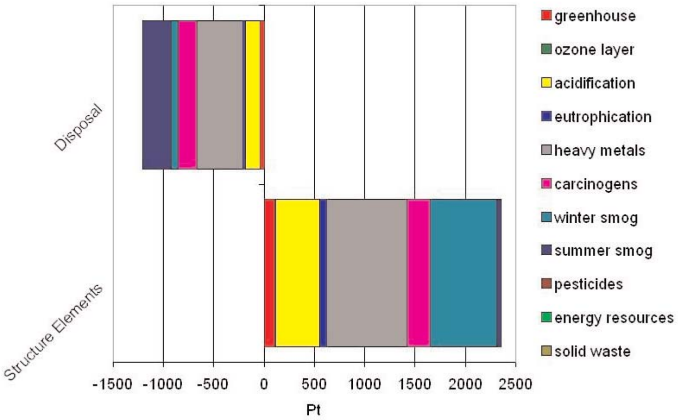

Figure 11. Construction and disposal inventory analysis for redesigned case study building 2, incorporating design alterations to facilitate deconstruction.

This reduction factor of 14% is attributed to several impact categories ranging from greenhouse gas emissions through to solid waste. Selecting the impact categories relevant to the worldwide goal of reducing global warming, a CO_2 reduction of 19.7% can be achieved by adopting a DfD approach. In real terms this equates to 94 tonnes of CO_2 for this particular building. It is important to note that these benefits/reductions in environmental impact and CO_2 production are applicable only after the first generation building has been dismantled and 95% of the structural steel sections reused. Operational energy has not been included as part of this study as the redesigned structures are intended to be as operationally efficient as the traditionally built case study structure.

5. CONCLUSION

The implications of design for deconstruction in the longer term are prosperous with regard to diverting material away from landfill and recycling processes. Second generation structures constructed using previously used steel sections are likely to enjoy the benefits of environmental impact neutral materials as they will be constructed using materials that have already been diverted from the steel recycling stream. Recycling steel is an energy intensive process and therefore, is a contributor to greenhouse gas production. The overall lifecycle environmental impact of a building in terms of CO_2 can be reduced by a further 19.7% if a design for deconstruction design approach is utilised. Furthermore, there is motivation on the part of the demolition industry to adopt a systematic deconstruction process, if the buildings are designed with reuse in mind.

The framework and infrastructure required to stimulate the reuse of building components is at present ad hoc and reliant on material reclamation and salvage. The growth of reusable component stock piles and depots is a distant objective that is relatively self developing. During the course of time, whilst the design for deconstruction buildings of today are constructed and occupied, they intrinsically store the components required to build future urban environments in a manner future generations deem fit. Furthermore, if the built environments of the future can yield reusable components, it is likely that dereliction and the number of brownfield sites will reduce as a result of the value offered by reuse in comparison to virgin materials.

Acknowledgements
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