Material change for a better environment

**WAS031 – Off site Construction – Client Exemplars**

# Waste Reduction through the use of Volumetric Construction at NATO Headquarters, Northwood

Volumetric construction reduced the waste generated in building multi-occupancy buildings to 5.5 $m^3$ per 100$m^2$ of construction: a reduction of 48% compared to traditional construction.

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The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

# Executive summary

The use of off site or Modern Methods of Construction (MMC) results in the production of less waste, but the evidence to support this is limited. To address this, WRAP have commissioned a series of case studies (WAS031 Off site Construction – Client Exemplars) which looks at different systems. In each case, the series seeks to address this issue by looking at the waste generated by the off site system on the building site and in the factory where it was produced, and comparing this with the waste generated by standard practice.

This study examines the waste from steel volumetric units produced by Caledonian Building Systems and erected by Caledonian to create single living accommodation as part of the Northwood redevelopment in Middlesex. Caledonian procure the chassis components, weld the modules and fit them out in the factory as far as external breather membrane and internal fixtures and fittings. Cladding and roofing on this project were also carried out by Caledonian, although these elements are potentially independent of the volumetric modules system.

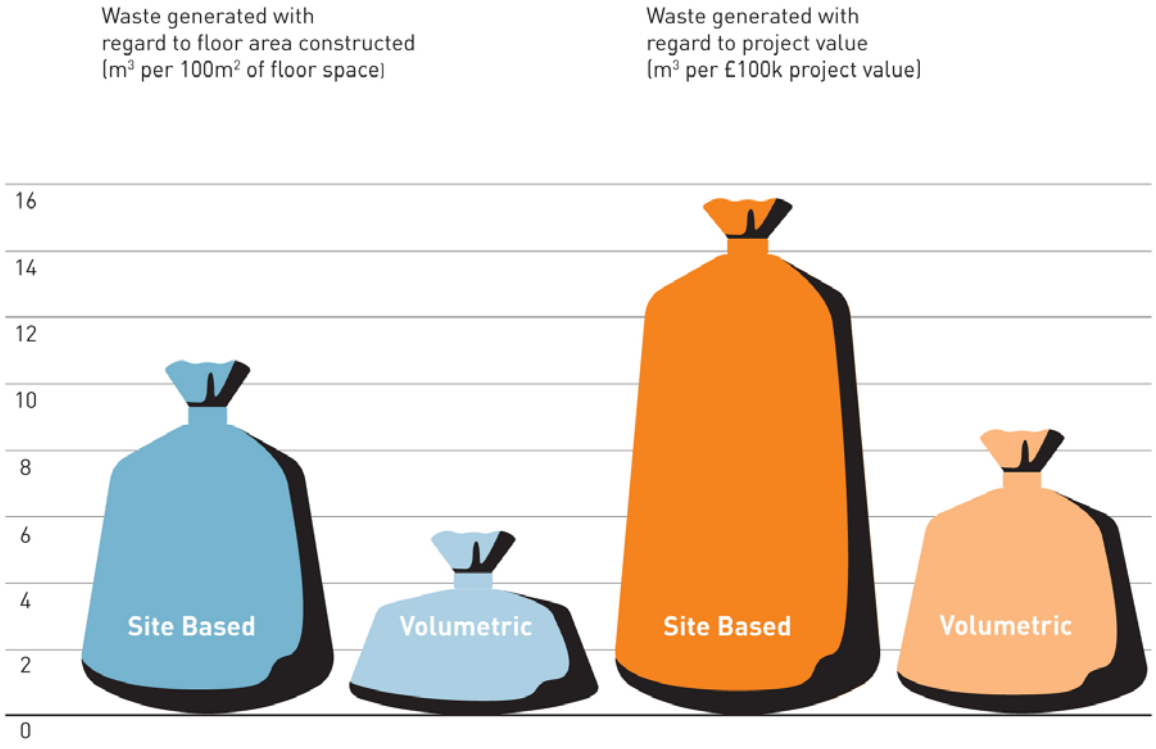
Waste data from both the Caledonian factory and the Northwood site have been collected and compared with construction waste from similar projects produced in traditional on site construction.

These volumes are then used to create:

- Environmental Performance Indicators (EPIs) by dividing the volume by floor area constructed to give waste in $m^3$ per $100m^2$ of floor space (roughly the area of a small house); and
- Key Performance Indicators (KPIs) by dividing the volume by the project value to give waste in $m^3$ per £100k project value.

Building in volumetric modules reduces metal, insulation, timber and plaster/cement waste compared to site-based construction. There is potential to reduce brick and concrete waste depending on the cladding systems applied. Packaging waste is increased, but consolidation at the factory facilitates recycling. A full breakdown is shown in section 3 of this report. By using a volumetric system at Northwood, it is estimated that the waste generated by this part of the project was reduced by 5.15 $m^3$ per $100m^2$ of floor space (48%) or 6.83 $m^3$ per £100k project value (44%).

Although the case study is of military accommodation, the Caledonian system is equally applicable to other repetitive accommodation types, including prisons, hotels, student and nurse residences.



# Contents

# 1.0 Northwood

## 1.1 Project description

### *1.1.1 Project profile*

| | |
|---|---|
| Client | Carillion Construction |
| Funding | PFI |
| Modular unit design and manufacture | Caledonian Building Systems |
| Contract value | £5,995,000 |
| Output | 166 bedrooms based on 105 modular units, gross floor area 6350m$^2$ |

### *1.1.2 Project background*

The Northwood project is the redevelopment of NATO Headquarters at Northwood, Middlesex. Caledonian Building Systems are involved with the provision of the new single living accommodation which is being provided in 3 separate phases. This case study focuses on accommodation comprising 166 senior rate en-suite bedrooms and ancillary communal areas such as lounge and utility rooms located over 5 floors accessed from a central modular core.

The building is clad with concrete block which is finished with a combination of cedar cladding and applied render finish. The roof covering is single skin profiled steel sheet fixed to a mono pitch roof structure over the modules.

The client for the project is Carillion Construction who secured the project on a PFI basis.

### *1.1.3 Scope Details*

Carillion provided all elements of the foundation and substructure design and construction. Caledonian were responsible for the design, supply, installation and completion of the modular superstructure including the external cladding and roofing works.

On completion of the Caledonian works, Carillion returned to site to complete the external works and landscaping.

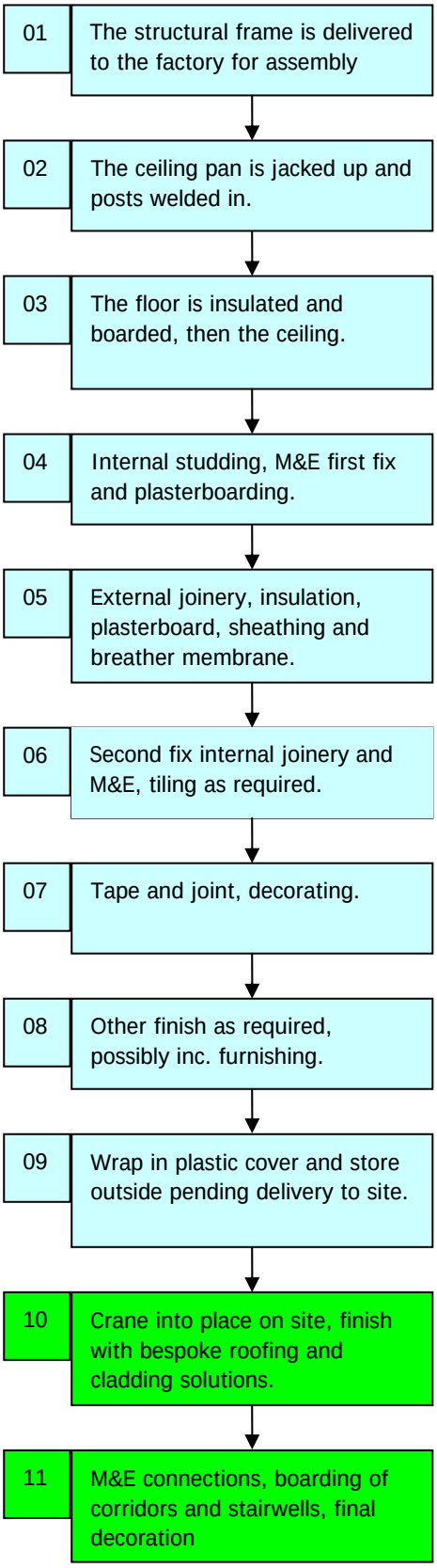
## 1.2 Reasons for using volumetric construction

Carillion had initially proposed a traditional construction method, but due to the overall scale of the Northwood Development project, Carillion were keen to reduce the number of various works packages and establish a degree of programme certainty for the critical path items, such as the living accommodation. The project is within one of the most secure military establishments in the UK. Modular construction has permitted a reduction in site labour numbers, site waste removal and general site deliveries.

Caledonian were in competitive tender with two other modular contractors and were awarded the contract on the basis of cost and a willingness to manage the ‘bolt on’ site activities such as the external cladding and roofing. Caledonian believe that the evidence from this project is that it is better to supply these elements as part of the modular system, to avoid having to coordinate different construction systems and work with traditional contractors who are unfamiliar with volumetric systems.

## 2.0 The Factory and Construction Process

This flow-chart shows the process from manufacture of the steel frame in the factory (blue) through to erection on site (green).



Caledonian modules are made from fully welded steel frames. Depending on the module type, the steel frame chassis may be laid out for a longitudinal plan (in which bedroom modules are placed either side of a corridor module) or a transverse plan (in which modules incorporate a bedroom either side of a short section of corridor. Finished module height rather than length and breadth is the principal transport restriction.

The chassis is taken into the factory for welding, beginning a production process cycle of up to 21 days. Steel joists are pre-fitted and posts are supplied to length.

Welded module prior to fit-out

Floor insulation and boarding.

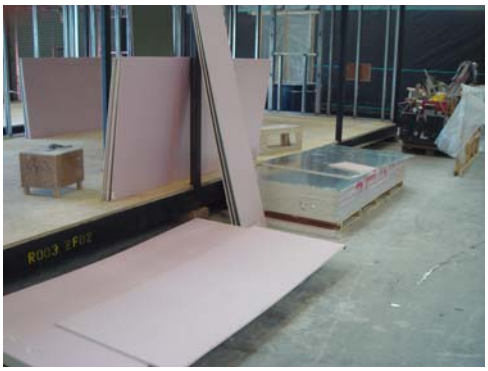
All trades – carpentry/joinery, electrical, plumbing, dry lining, decorating and other finishing trades as applicable (eg. tillers, carpenters) come to the module. Production is organised around the module rather than sequential operations on a line. The process brings all the trades in turn to each module, each one effectively a miniature building site in a controlled indoor environment. This is true of all four factory units and all module types. Because there is no production line as such, there is no need for a change of tooling or process between jobs.

Floors are insulated with Isover glasswool, and boarded with OSB, which is also used for external sheathing. Some waste of boarding and insulation does occur, but there are opportunities for reuse within the factory.

Internal partitions are of steel studwork, supplied to length, and lined with plasterboard.

There is a high proportion of plasterboard waste (approximately 33% of all plasterboard supplied) from the Caledonian process, which is due to a number of factors. Plasterboard is normally delivered on bearers made from strips of plasterboard – these together with the top and bottom boards (which have been damaged by banding straps) are discarded. A major source of waste is the practice of boarding across door and window openings with a double skin of staggered plasterboard, after which the opening is cut out and the plasterboard recycled. This is intended to avoid joint cracks around openings from the use of cut boards. Further waste is generated by the use of large or full boards for reveals, and by cutting taper edge boards to use the tapered edge, with the rest of the board being wasted. Sasmox gypsum-bonded wood particleboard (83% gypsum) is used as an alternative to plasterboard in prison modules. Sasmox offcuts were formerly incorporated into the module walls to provide fixing grounds. They are now treated as a waste stream.

Door cut-out: more than one sheet of plasterboard is discarded for each doorway.



Plasterboarding results in many off-cuts of different types

A number of steps are now being or have recently been taken to reduce plasterboard waste (see section 3.3). All plasterboard waste is segregated and sent for recycling.

Packaging waste from insulation, joinery and carcassing, filling and decorating compounds is segregated within the factory and waste management chain for recycling (see section 5.3).

Plastic wrap segregated at the module for baling

Sealant cartridges segregated within the factory for shredding and recycling

Depending on the contract, different levels of internal fit-out will be completed at the factory. Where provided, carpeting and tiling is designed to make use of standard sizes with minimal off-cuts. Although the norm is to carpet on site and avoid damage in the factory, some jobs are supplied as a “room in a box”, in which case a locked-door principle is applied to minimise the risk of damage.

Finished bathroom: plumbed and tiled at the factory

All modules have full breather membrane externally (heat reflective for outer walls) and are fully wrapped for storage at the factory pending delivery to site.

Modules with external joinery, sheathing and breather membrane fitted.

Modules ready to leave the factory

The units are delivered to site with appropriate fixing points added to facilitate site-added cladding systems. Services between units are connected on site with central corridors used as horizontal distribution routes. Individual modules are connected on site to ensure correct positioning and structural continuity. Once interconnected, the modules form the full structure of the building. Other techniques, which include panellised elements and linkage to traditional forms of construction (eg. in situ concrete and steel structures) for non-modular areas, are also employed by Caledonian.

## 3.0 Waste Comparisons with Traditional Build

### 3.1 Data

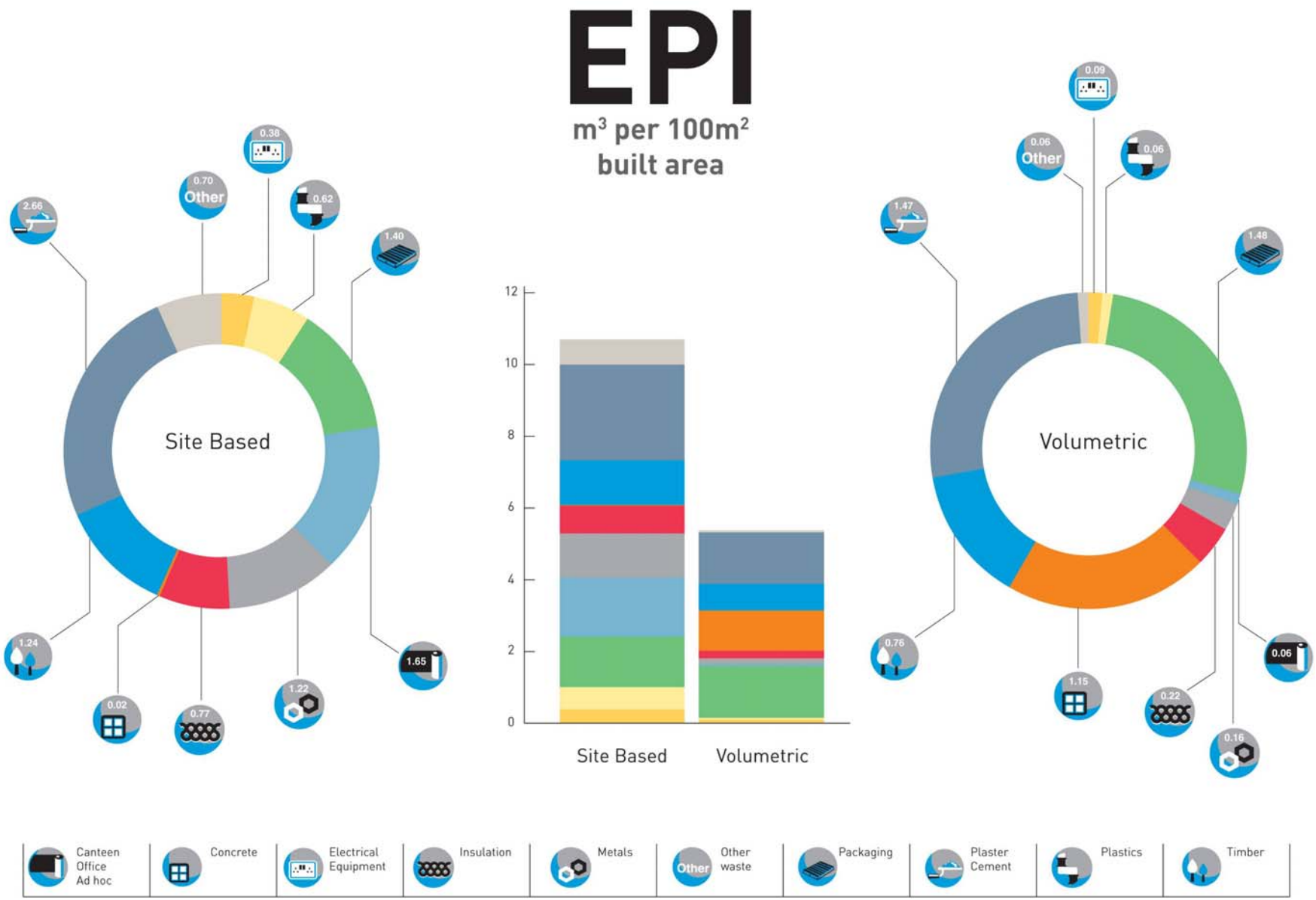
Data was collected on volumetric construction (on site and in the factory) and site-built accommodation of similar type[1] using BRE's SMARTWaste system which classifies waste into 14 categories (see table below). SMARTWaste can be used to produce Environmental Performance Indicators (the waste by volume with regard to the floor area and Key Performance Indicators (the waste by volume with regard to project value).

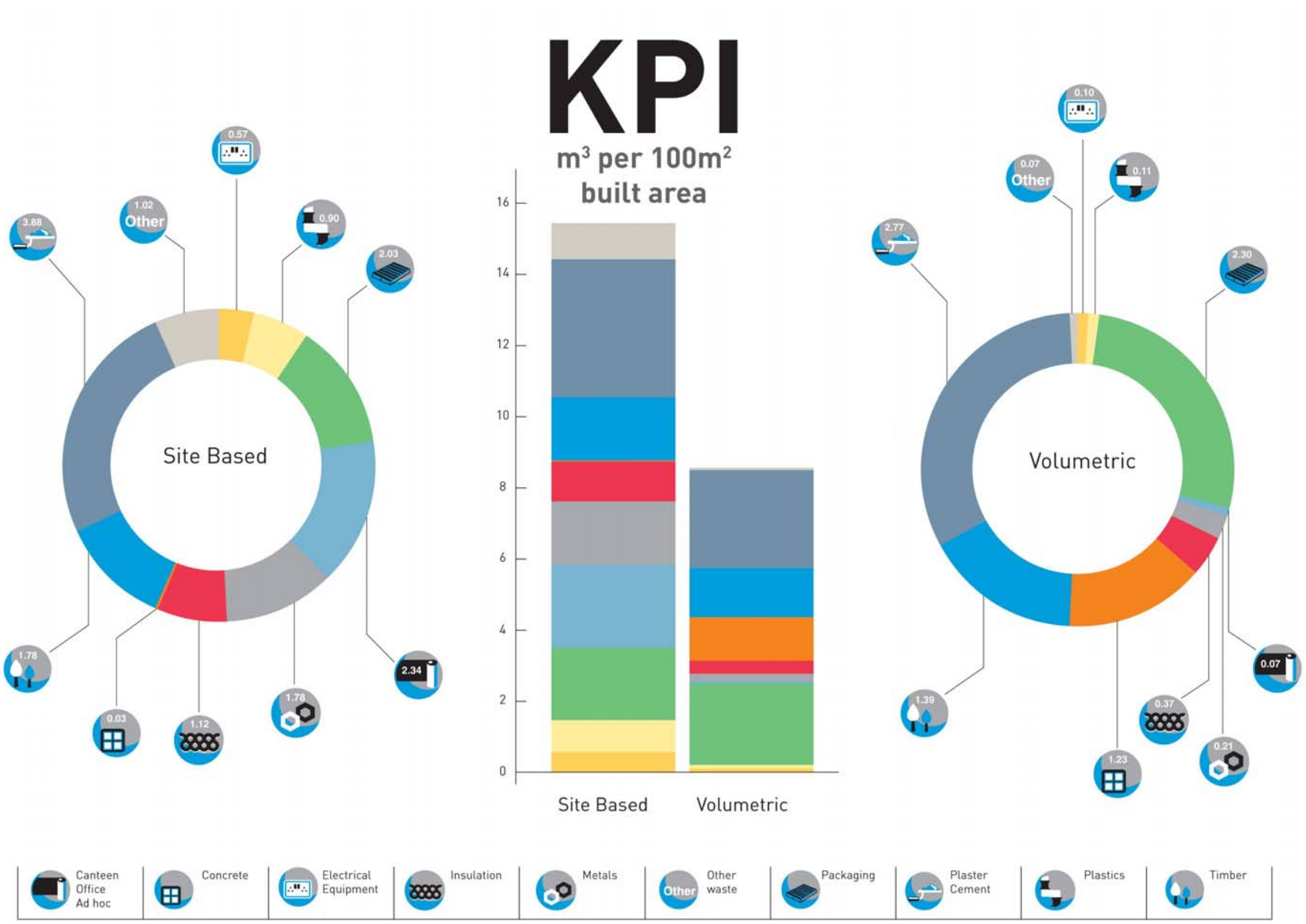
| | EPI | | KPI | | Reasons for results |
|---|---|---|---|---|---|
| | Waste generated with regard to floor area constructed ($m^3$ per 100$m^2$ of floor space) | | Waste generated with regard to project value ($m^3$ per £100K project value) | | **Green figures indicate an improvement in waste efficiency Red figures indicate a drop in waste efficiency** |
| | Site based | Volumetric | Site based | Volumetric | |
| **Ceramics/bricks** | 0.41 | 0.00 | 0.59 | 0.00 | No bricks used in this project |
| **Inert** | 0.00 | 0.00 | 0.00 | 0.00 | |
| **Electrical Equipment** | 0.38 | 0.09 | 0.57 | 0.10 | Modular wiring factory fitted |
| **Liquids and Oils** | 0.00 | 0.00 | 0.00 | 0.00 | |
| **Plastics** | 0.62 | 0.06 | 0.90 | 0.11 | Modular fittings, factory environment |
| **Packaging** | 1.40 | 1.48 | 2.03 | 2.30 | Includes packaging of modules themselves |
| **Canteen/office/ad-hoc** | 1.65 | 0.06 | 2.34 | 0.07 | Majority of works in controlled factory environment |
| **Metals** | 1.22 | 0.16 | 1.78 | 0.21 | Majority of metalwork supplied to required sizes |
| **Insulation** | 0.77 | 0.22 | 1.12 | 0.37 | Insulation fitted in factory (more controlled) |
| **Concrete** | 0.02 | 1.15 | 0.03 | 1.23 | Waste from blockwork cladding |
| **Hazardous** | 0.01 | 0.06 | 0.02 | 0.07 | |
| **Timber** | 1.24 | 0.76 | 1.78 | 1.39 | Principal site waste is cedar cladding |
| **Plaster/cement** | 2.66 | 1.47 | 3.88 | 2.77 | No wet plaster/cement in modules |
| **Furniture** | 0.28 | 0.00 | 0.41 | 0.00 | Furniture factory fitted |
| **Total** | **10.66** | **5.51** | **15.45** | **8.62** | |

For the purposes of comparison between the construction approaches, inert waste from groundworks has been excluded from this table.

The reasons for waste differences are discussed further in section 3.2.

[1] *The best waste data available for comparison was taken from two hotel projects recorded using the BRE SMARTStart system.*


EPI
m³ per 100m² built area
Site Based
2.66
0.70 Other
0.38
0.62
1.40
1.65
1.22
0.77
0.02
1.24
12
10
8
6
4
2
0
Site Based
Volumetric
Volumetric
1.47
0.06 Other
0.09
0.06
1.48
0.06
1.15
0.22
0.16
0.76
Canteen Office Ad hoc
Concrete
Electrical Equipment
Insulation
Metals
Other waste
Packaging
Plaster Cement
Plastics
Timber


KPI
m³ per 100m² built area
Site Based
Volumetric
0.57
1.02
Other
0.90
2.03
3.88
1.78
0.03
1.12
1.78
2.34
0.10
0.07
Other
0.11
2.77
2.30
1.39
0.37
1.23
0.21
0.07
16
14
12
10
8
6
4
2
0
Site Based
Volumetric
Canteen Office Ad hoc
Concrete
Electrical Equipment
Insulation
Metals
Other waste
Packaging
Plaster Cement
Plastics
Timber

## 3.2 Reasons for the different results

### *3.2.1 Ceramics/bricks: reduced waste*

No bricks were used on this project as cladding was in blockwork, render and cedar.

### *3.2.2 Electrical equipment: reduced waste*

Modular wiring is fitted at the factory, with re-use of materials by subcontractors, and minimal connections made on site.

### *3.2.3 Plastics: reduced waste*

The main use of plastics in the Caledonian process is in packaging, therefore these are included in the next category.

### *3.2.4 Packaging: increased waste*

This includes the covers in which the modules are wrapped at the factory and which are skipped as site waste on site.

Door sets supplied with timber bearers, plastic wrap and cardboard

Covers for finished modules at the factory

### *3.2.5 Canteen/office/ad-hoc: reduced waste*

The main reasons for a large reduction in this waste category are thought to be that an estimated 75% of the project (by value) is completed within the controlled factory environment, with efficient use of labour and tighter management of materials.

### *3.2.6 Metals: reduced waste*

Although the Caledonian system is based on extensive use of steel, most of this is supplied prefabricated. Caledonian's metal fabrication is generally restricted to roof structures, including bracing of supplied roof modules. Steel studwork is cut to length from a mother coil and supplied to order for module heights. Plumbing contractors re-use or recycle copper waste.

### *3.2.7 Insulation: reduced waste*

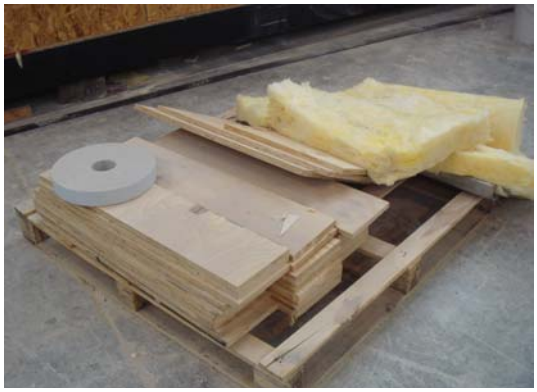
All modules are factory insulated using Isover glasswool. Installation in a controlled factory environment reduces waste since the material is cut to regular lengths, worked in a clean, dry area (reducing damage) and any off-cuts from one unit can easily be incorporated into the next unit being made.

### 3.2.8 Concrete: increased waste

There is an apparently anomalous result with respect to concrete waste, which is principally from the external blockwork cladding to the MMC construction. In principle, there is no reason for concrete waste from site-based works (including foundations and cladding) for MMC to differ from that for conventional construction techniques, and the absence of concrete from the above-ground structure should contribute to an overall reduction in average concrete waste. It should be noted that certain waste results for MMC (including concrete, ceramics, plaster/cement, metal and timber) will differ according to the roofing and cladding systems specified by the client and by the proportion of MMC structure to site-built core areas and ancillary works.

### 3.2.9 Timber: reduced waste

Some OSB sheathing/flooring boards are made to size for the modules, and there is reuse where possible of offcuts within the factory for pattressing etc. The principal source of timber waste on this project is from external cladding.



Ply offcuts at the factory retained for possible re-use

### 3.2.10 Plaster/cement: reduced waste

The Caledonian process minimises wet trades and overall waste figures are lower for this material group. The principal waste stream is off-cuts and damaged plasterboard from the factory which is sent for recycling. The only plasterboarding normally performed on site within the modular areas of the construction is the final skin on corridors and multi-level core areas.

## 3.3 Scope for reducing waste further using the volumetric steel system

A number of steps are now being or have recently been taken to reduce plasterboard waste. The need for tapered edges has been reduced by changing dry lining practices to feather out jointing compound over a greater width of board.

Up to the present, several different types of plasterboard are in use for fire, moisture and sound resistance. These are to be replaced by a single multi-purpose board (Lafarge Megadeco) which will facilitate greater reuse of offcuts and spare boards, since all boards will be of the same type. Waste savings of 20-25% are predicted, which will offset the additional cost of Megadeco. From a quality control perspective, it is also expected that this will eliminate the possibility of board types being used in the wrong application, which is possible where a range of similar-looking boards is in use.

Damaged plasterboard waste could be reduced by better working practices and packing/delivery systems.

The factory paint sprayshop is now moving from large paint tins to 1,000-litre IBCs (Intermediate Bulk containers). This will eliminate waste paint tins.

In principle, the more control Caledonian is able to exercise over design and sizing, the greater potential there would seem to be to reduce waste through the use of modules based upon standard sheet sizes for plasterboard and flooring boards.

As part of an ongoing carbon footprinting exercise, Caledonian are considering responsible sourcing and recycled content of materials (timber products are already FSC certified and recycled aggregate is preferred over virgin for sub-bases and site roads).

Re-siting of Caledonian modules is not considered a practical proposition because they are embedded in conventional roofing and cladding systems, however, Caledonian are working towards an end-of-life statement.

# 4.0 Where Volumetric Systems are Used

## 4.1 Extent of usage

Permanent volumetric units have on the whole been made by companies also producing relocatable units this makes estimating the size of the market difficult. The turnover of the sector is estimated at £414 million which is 28% of the off site construction industry (Off site Industry Survey 2006, *Buildoff site*).

## 4.2 Types of projects in which volumetric construction is used

Volumetric construction is almost exclusively made from steel, either light steel frame or hot rolled section. It is mainly used for bedrooms in multiple occupancy (hotels, student accommodation, prisons etc), but also has applications with flats, houses and fast food outlets. The maximum heights of these buildings vary from manufacturer to manufacturer, but are typically:

- Between four and six stories for light steel units with no other structural support
- Up to 10 stories for light steel units using concrete or hot rolled stairwells
- Up to 17 stories for hot rolled units

As a build method it is normally adopted by those who value speed, reliable construction times and high quality.

## 4.3 Strengths and weaknesses of volumetric construction

### *4.3.1 Transportation*

Transportation is a major consideration that needs to be accounted for in volumetric construction far more than with other methods.

### *4.3.2 Quality*

It is likely that volumetric units will have a greater conformity to the original design than other forms of construction. This will be important when considering thermal and acoustic insulation and airtightness performance, as these are particularly difficult to rectify once the building has been completed.

In addition volumetric units have the advantage over other methods of building in that the finishes can be applied in a controlled environment.

### *4.3.3 Speed and minimisation of disruption*

It is difficult to quantify the speed advantage of volumetric systems. However it is not unusual for buildings to be built in the half time of that achievable by conventional methods. They are particularly effective when used on sites in city centre areas where there is minimal site storage and the working day is curtailed.

### *4.3.4 Sustainability*

Volumetric building has some strong environmental credentials. Waste has already been discussed in this report, but there are other areas:

- Steel typically has a high recycled content[2], but also high embodied energy. There is potential for non-structural frame elements in the Caledonian system to be replaced with timber (ceiling joists and studwork), and this is now being considered.
- The depth of the frame can be easily adjusted to accommodate a variety of insulation thicknesses
- Room-by-room sign-off on quality control of insulation and caulking ensures optimum airtightness and thermal insulation so reducing operational impact.
- As for most off site methods, consolidation of material deliveries to a single factory potentially reduces transport chains compared with site-based construction.

The low thermal mass of volumetric structures may be problematic and leaves them vulnerable to overheating. However low thermal mass can be advantageous where the occupants want rooms to cool down quickly (eg bedrooms). Overheating can be compensated for by well designed shading and ventilation.

### *4.3.5 Design input*

The undoubted advantages of volumetric units can only be realised with increased design discipline and which allows the design to be frozen early in the process.

## 5.0 Caledonian and their Facilities

### 5.1 Background

Caledonian specialises in the design, manufacture and construction of permanent, multi-storey buildings using off site modular construction. The company operates as both Principal Contractor and Modular Sub-Contractor, constructing projects with values between £1M and £50M. Caledonian is the largest off site constructor of permanent buildings in the UK, with a turnover in excess of £130M.

Operating from a 42 acre site near Newark in Nottinghamshire the Caledonian facility comprises 4 separate factories, each producing modular units, enabling 4 independent projects to be processed at any one time. Each factory is approximately 120,000 sqft in size and each is capable of producing over 200m$^2$ of accommodation building per day. The site is operating at full capacity and a fifth factory is being planned.

### 5.2 Current waste management practices

Caledonian have recently appointed a waste management contractor (Mid UK Recycling Ltd) with whom they have implemented a zero-waste-to-landfill strategy for all wastes collected from the Newark production facility. To minimise contamination of segregated skips, only trained staff are allowed to put materials into the skips.


[2] *However it should be noted that the high grade steels (S225, S235) used in Caledonian's structural chassis may have a lower recycled content than other grades.*

There is primary segregation of the following materials:

| Material | Collection regime | Processing and end uses |
|---|---|---|
| Wood | segregated ro-ro bins | currently chipped for recycling in fibre products, in future will go to energy-from-waste |
| Plasterboard | segregated ro-ro bins | paper and foil stripped (approx 10% of plasterboard is foil-backed, pending introduction of multi-purpose board): paper recycled for pulp, foil recycled; gypsum recycled in cement manufacture |
| Sasmox board | segregated ro-ro bins | Bio-MRF and composted for fertiliser base |
| Packaging materials | card/paper and plastics baled on site | Large section rigid plastics shredded and recycled in extrusions; general plastic waste becomes RDF for cement kilns |

There is secondary, post-site segregation of the following materials:

| Material | Processing and end uses |
|---|---|
| Metals | recycling |
| Green waste | composting |
| Inert | reused |
| Misc packaging | RDF |

On site, every project has a Site Waste Management Plan.

Segregated skips at the factory


A baler is used to minimise disposal costs of plastic, card and paper

Baled plastic wrap ready for collection at the factory

## 6.0 Conclusion

Volumetric MMC is a rapidly growing form of MMC. Its use allows for reduced time on site and greater completion date reliability. Therefore on projects with critical end dates, with cash flow considerations (eg earlier rental incomes) or on sensitive inner city sites with minimal storage and curtailed working days volumetric solutions are increasingly popular.

This case study has compared the amount of waste produced in constructing a complete volumetric building at Northwood and added this to the amount of waste produced in the factory that made the volumetric units (Caledonian Building Systems). This was compared to the amount of waste normally produced by building using traditional on site methods. It could be argued that this unfairly penalised the off site method, but even under these circumstance the waste generated was dramatically reduced by 5.15 $m^3$ per 100$m^2$ of floor space constructed (48%) or 6.83$m^3$ per £100K project value (44%).

Caledonian have recently implemented a zero-waste-to-landfill strategy with their waste management contractor Mid-UK Recycling. They are segregating wood, plasterboard, Sasmox board, packaging materials, metals, green waste and inert materials into different skips. Only trained personnel are permitted to put material in the skips to minimise contamination.

Making volumetric units in a factory aids in the minimisation and segregation of waste when it is produced. By using volumetric units less raw material is handled, cut and fitted on site and this also reduces the waste produced. Therefore there is no reason to believe that similar savings in waste to those obtained in this report would not be seen on other projects building barracks, hotels, student accommodation and other similar multi-residential buildings.

**Written by:** Jon Mussett, Christopher Gaze
**Photographs:** All factory photographs by BRE except for aerial view, factory floor view and lorry. All other photographs including Northwood site by Caledonian.


Published by
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The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

www.wrap.org.uk