Information Paper 9/13

Lessons from AIMC4 for cost-effective, fabric-first, low-energy housing

Part 4: Understanding value, applying lean techniques and benchmarking

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This Information Paper is Part 4 in a series of four papers about the AIMC4 applied research project, which was created to research, develop and pioneer the volume production of low-carbon homes for the future that would achieve Level 4 (energy) of the Code for Sustainable Homes without the use of renewable energy.

Part 1 introduces the AIMC4 project and describes the process of translating its objectives into innovative solutions to meet the project targets. Part 2 covers the supply chain development phase of the project – the process of working with suppliers to develop products and build solutions to meet the technical specification. Part 3 focuses on developing detailed technical specifications for the homes. Part 4 focuses on understanding value for the end user and making the construction process as efficient as possible.

This series of Information Papers seeks to draw together the AIMC4 story in one place as a reference point for industry, government and other stakeholders. The lessons learned cover issues that are relevant to the volume production of low-energy homes, which will be important for all builders and developers as regulations develop in the future.

Introduction

After shortlisting suppliers to provide products for the AIMC4 homes (see Part 2), there was the opportunity to develop new approaches to buildability, to reduce costs and to improve the commercial viability of the possible solutions. There were three key stages:

1. The use of BRE's Construction Lean Improvement Programme (CLIP) master engineers to facilitate interaction between suppliers to examine product integration through Design for Assembly (a lean design tool; see below). This stage was completed during the design process but before construction began.
2. Collaborative planning. This was completed at the beginning of the construction stage. It focused on the construction programme and opportunities for efficiency improvements on site through improving work interfaces and site relationships. This involved product suppliers as well as the site management and the subcontractors who provided the labour to install the products.
3. Collection of data during the construction process using BRE's CALIBRE[1] tool, a construction process measurement method, and using this to highlight areas for improvement using CLIP.

Figure 1: Stewart Milne Group's Preston site homes

BRE's lean improvement tools and techniques

BRE has produced a number of different tools and techniques that enable lean practice to be embedded within an organisation or project. One definition of 'lean' is that it is a philosophy and practice of ongoing identification and elimination of waste, involving everyone in the organisation. Figure 2 shows this concept in terms of cost, although the benefits extend much more widely than this. Under normal conditions, waste is an integral part of activities and often invisible. Lean thinking uncovers the waste and makes the team more conscious of it, so that the amount and root causes of waste can be understood and then systematically eliminated.

In this context ‘waste’ has a very precise meaning. Waste is anything that does not directly contribute to the value of the product (in this case, the home). Value increases as the home grows (ie when construction occurs that does not involve waste). In general terms, waste can be categorised into ‘the seven wastes’ described in Table 1.

The removal of wasteful activities from a process has positive impacts on time, cost, quality, health, safety and sustainability of the project. Creating efficient processes also reduces physical waste in terms of materials, energy and water, and has a beneficial effect on the surrounding community through the reduction in noise, vehicle movements and unnecessary disruption. Particular production and sustainability issues are addressed within the process improvement activity, as all goals and targets for the project are considered when creating the optimum process, so that no one improvement is implemented at the expense of the project as a whole.

The suite of lean tools and techniques available from BRE that apply this waste removal approach include lean design (Design for Assembly), a number of data collection tools (CALIBRE and SMARTAudit) and other diagnostic and workshop tools developed by BRE CLIP. BRE CLIP was established in 2003 to support the UK construction industry in its drive to improve financial performance, provide a better product and service to its customers, and cope with a skills shortage. The CLIP approach is not based upon a traditional consultancy and training model, but uses practical intervention to deliver tangible improvements in terms of cost, quality and project delivery. Alongside these measurable improvements, the tools and techniques developed specifically for the construction sector help to address industry issues such as:

- integration of design and construction
- collaborative planning for improving quality and reducing lead times on site by addressing such things as task interfaces and relationships between contractors
- defect-free delivery
- resource efficiency and waste
- sustainability.

Each of the tools used on the AIMC4 project is explained in detail in the relevant sections of this paper.

Figure 3 illustrates how BRE’s lean tools were used together on AIMC4 to develop an understanding of waste, and thereby improve the efficiency of projects.

Application of lean techniques at key stages

One of the keys to the success of lean improvement on the AIMC4 project was that the approach was embedded at the very start of the project, and maintained throughout. At each stage of the project, different tools and techniques were used for best effect; from understanding the value of the homes and Code 4 benefits to the occupants, through to learning and implementing improvements. Figure 4 shows the phases of the AIMC4 project from detailed design and the lean tools that were used at each stage.

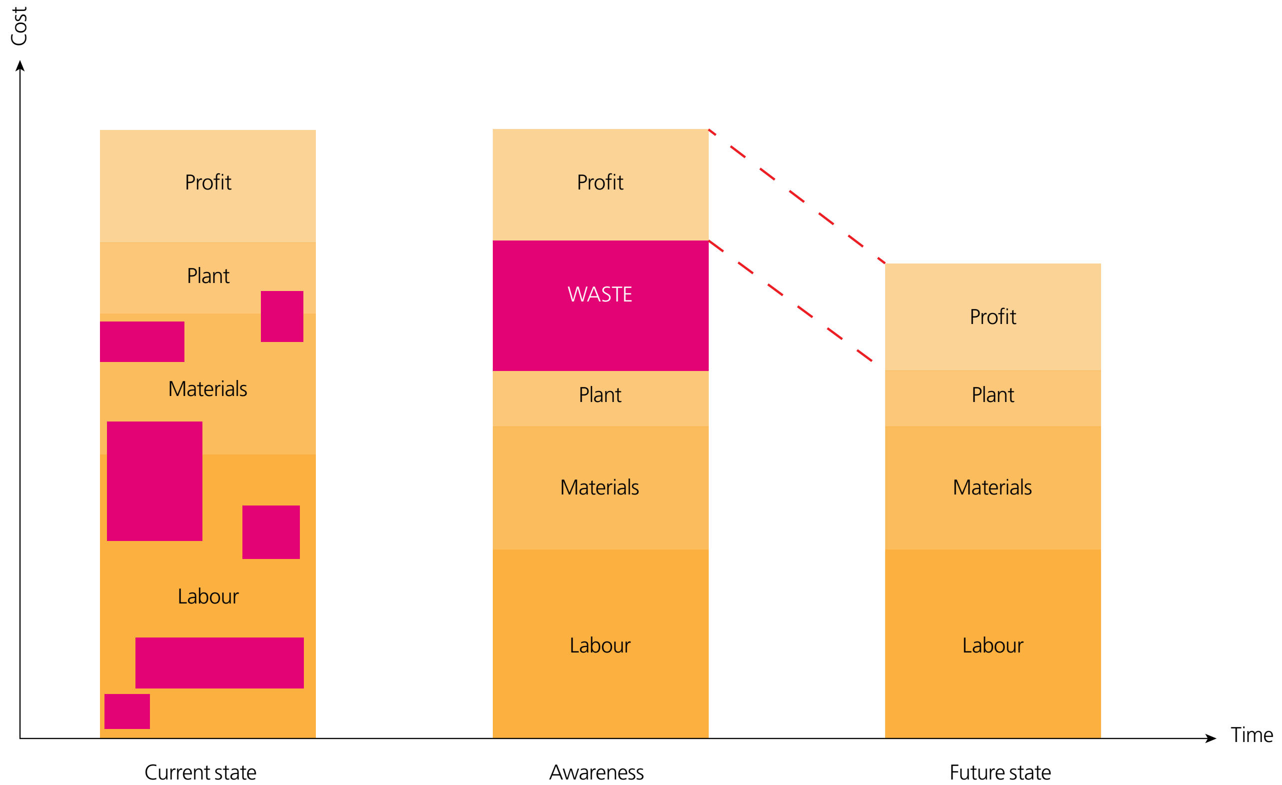


Figure 2: Lean waste removal in cost terms

Table 1: The seven wastes

1	Waiting	For anything: information, material, decisions or previous trade
2	Overproduction	Doing too much or at the wrong time, eg fully completing a piece of design before confirmation of sizes or closing a plasterboard wall before the electrics have been fully installed
3	Rework	Including defects, quality issues and design iterations
4	Motion	Excessive personal motion: how much does a person need to move about to do their task?
5	Process	An overcomplicated process, or using the wrong tool for the job
6	Inventory	Too much or too little stored, or incorrect method of storage of materials or information
7	Transportation	Excessive movement of materials, plant and information

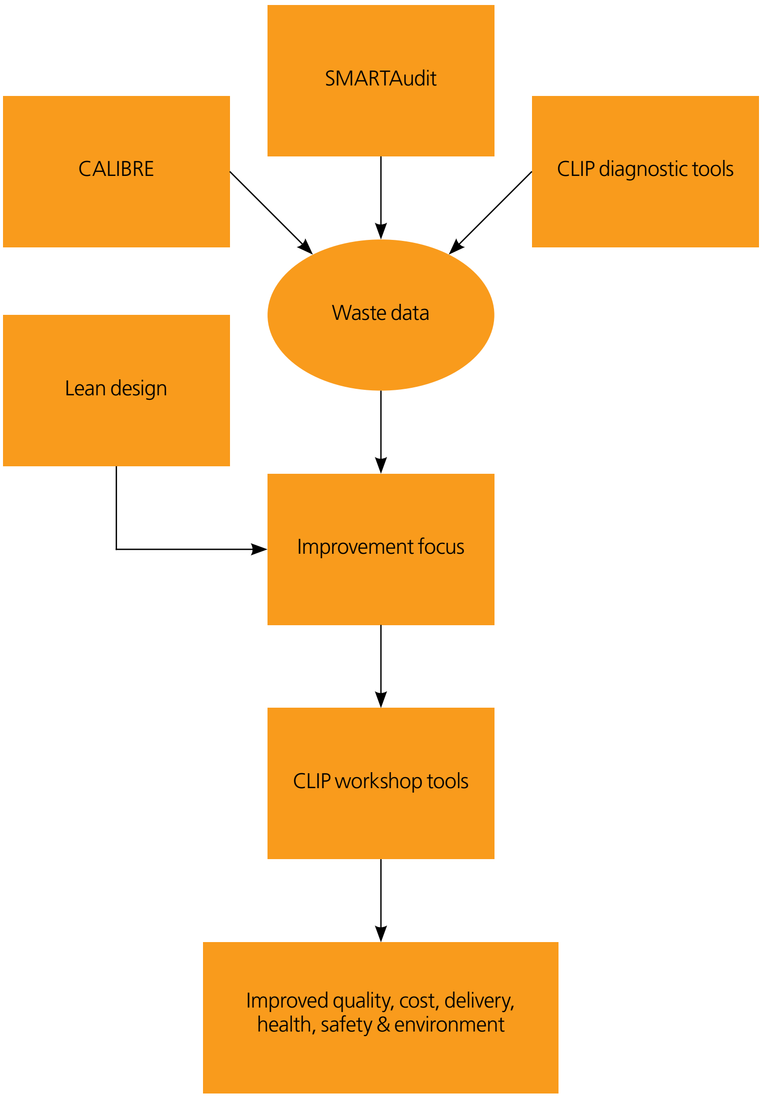


Figure 3: The interaction of BRE's suite of lean tools

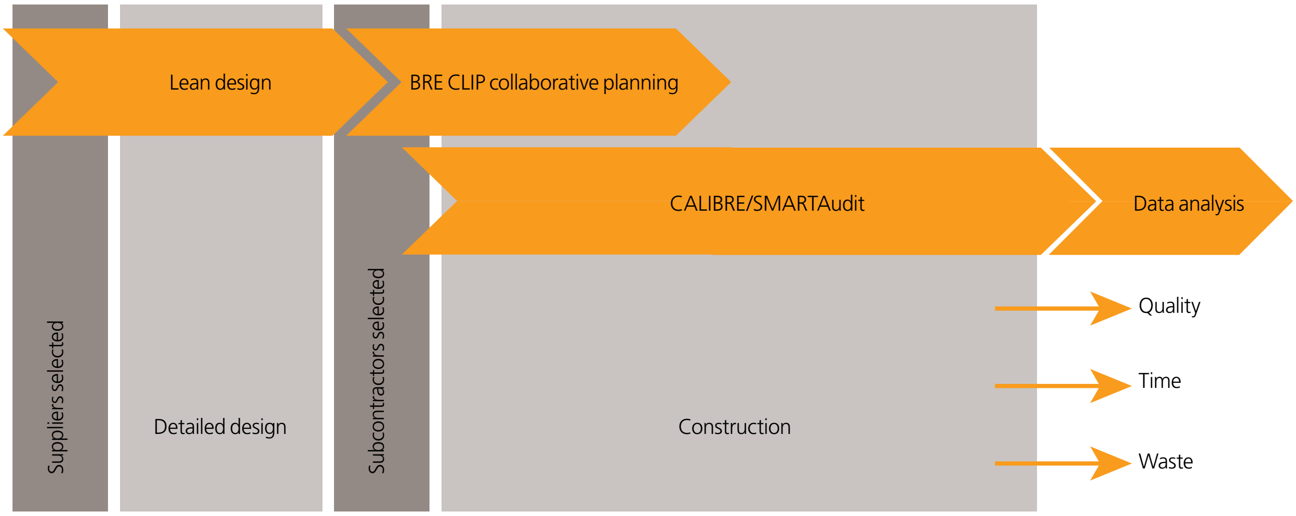


Figure 4: Project stages and application of lean techniques

Once the suppliers had been selected through the innovative 'sandpit' process (see Part 2), the first techniques were implemented. Lean design was one of the first concepts; this started the project teams thinking about 'lean' as an additional mechanism through which they could achieve the performance and cost targets of the project.

Once the subcontractor teams were selected and the construction phase was about to start, BRE CLIP held collaborative planning workshops with the site management and the tradespeople. These workshops focused the project teams on quality to achieve the design performance, whilst improving the time and cost outcomes.

From the start of the construction phase, both CALIBRE and SMARTAudit were put in place to capture the key data for each site. This fed into the final data analysis phase and recommendations for further improvements.

Each step in the project is explained further in the following sections.

Understanding value from the outset of the project

Lean techniques can only be truly effective when both business and customer value are understood and used to drive decisions throughout the process. When seeking to deliver innovative and technically advanced homes, understanding the concept of the next person in the value chain being the 'internal customer' in addition to the end-use customer is key. The target technical criteria for the various building elements can be defined using test data and computer modelling. However, the more complex issues, such as buildability, reliable commissioning and performance during use, represent a much greater challenge.

From the start the consortium has focused on delivering value to the private customers of the homes and, in the case of three of the homes, the housing association and its tenants. The use of a 'fabric-first' approach has been core to this and requires the minimum amount of intervention from those who are going to live in the homes.

Consumer focus groups

A number of focus groups were held in the areas where the project houses were to be built. Each was attended by a number of homeowners covering a wide demographic range. The focus groups each looked at different products that could potentially be used on the project; these included boilers and boiler controls, domestic heating and hot water controls, mechanical ventilation with heat recovery (MVHR) systems and windows. The focus groups were used to test the perception of the products in terms of appearance and cost, and how easy they were to use.

These groups added a valuable user's view to balance the technical performance information already known for the products. This combination of information allowed the project team to take a wider view of the value of the products and was used to expand procurement discussions. For example, the information gathered highlighted that:

- some of the heating control suppliers answered questions about 'user feedback' in relation to installers on site, not the people who will live in the homes
- some of the boiler suppliers acknowledged that their standard control units were seldom used by heating installers but they continued to include them within their standard package, which added an unnecessary cost
- several of the MVHR system suppliers did not have a clear strategy to deal with the need for annual filter replacements or provide easy-to-view warning mechanisms within the living space to prompt the occupants to change the filters themselves.

One of the reasons for a fabric-first approach is to minimise risk: risk to the occupant, ie the house should function properly and safely, be easy to control and require the minimum of maintenance; and risk to the developer, through methods such as reducing the need for specialist trades and skills, unfamiliar technologies, and ensuring customer acceptability and desirability. To help develop thinking in this field, the consortium developed the matrix shown in Figure 5. This complemented the customer focus group work.

The vertical axis represents installation risk, low at the bottom where existing skills can be used and high at the top, where new skills and possibly new trades are required. The horizontal axis

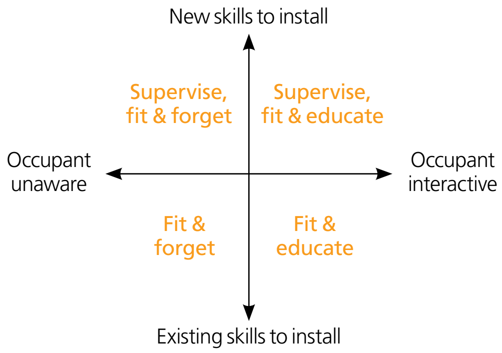


Figure 5: Occupant and installation risk of product selection

represents the risk to the occupant. At the left-hand end they are completely unaware of the product being in the house. At the right-hand end they have to be actively interacting with the product to get it to perform.

The bottom-left quadrant represents true fabric solutions that can be installed with existing skills, eg triple glazing. Such products are described as 'fit and forget'.

The bottom-right quadrant describes those products that can be fitted using existing skills, but require the occupant to interact with them. A good example might be traditional zone-controlled central heating. Such products are described as 'fit and educate'.

The top-left quadrant is for new products that do not require interaction with the end user, and require new skills or subcontractors to install. An example is waste water heat recovery; end users do not know it is there, but plumbers have to learn some new skills to install it. Such products are described as 'supervise, fit and forget'.

The top-right quadrant is for those products that both require new skills to install and are reliant on end-user interaction. These are the highest-risk products. An example would be MVHR, which requires new skills to fit and also needs to be looked after and maintained by the end user. Such products are described as 'supervise, fit and educate'.

Product supplier Design for Assembly lean workshops focusing on technology type

Lean design

Lean design is a concept that aims to deliver better-quality products at a reduced cost by:

- improving design and build processes
- designing out waste in activity and materials through Design for Assembly.

It takes the principles of 'lean' and applies them to the process of designing components or systems. The idea is to minimise the number of components and to simplify the method of assembly or fabrication to make it more reliable and easier.

Two lean design workshops were held for the AIMC4 project and they brought together architects, designers, suppliers and contract managers to be introduced to the ideas and concepts around lean design. They examined aspects of performance and buildability, particularly around the interfaces and junctions that needed to be considered during the design and construction of the homes.

The workshops analysed different construction methods: one focused on timber-frame construction, the other on masonry. Both gave the partners an opportunity to assess the potential issues around assembly elements of the build, both on and off site, and a chance to optimise specifications so that they achieved the desired energy targets at minimum cost.

Particular emphasis was put on junctions between walls, floors, roofs and fenestration, which are vital, particularly with new products that have not been used much in the past. Participants took part in a number of practical exercises, including building a house out of toy bricks (Figure 6) to stimulate thinking about Design for Assembly principles such as controlling the number of components, foolproofing assembly and ease of component alignment.

> *The lean workshops neatly highlighted the concept and encouraged us to think differently about the design process and the impact on buildability on site. The concept extends beyond the AIMC4 project and we hope the learning gained can be applied across the wider business.*
>
> Sustainability manager

The Design for Assembly workshops were followed by practical demonstration and testing days where integration and prototypes were trialled (Figure 7). One of the fundamental principles here was that individual companies each arrived with their 'product' and, by the end of the process, had collaborated to give the housebuilders 'system solutions'. The installation of windows into walls is a critical area in terms of potential heat loss. The initial 'sandpit' and Design for Assembly workshops emphasised how important it is to integrate the wall construction, insulation, cavity closure, airtightness barrier and the build process for best overall performance. Following the first workshops, the most innovative suppliers worked in teams with the suppliers of the other components, and returned to the follow-up workshop with combined offerings that worked as a system and could be fitted by one team.

Figure 6: An exercise to challenge design assumptions at a lean design workshop

Figure 7: Trialling workshops

Figure 8: A collaborative plan in progress

Site-based collaborative planning with the supply chain

What is collaborative planning?

Collaborative planning is one of BRE CLIP's key lean techniques and is used as both a diagnostic and waste removal workshop tool. The technique aims to utilise existing skills and experience in the project delivery team to:

- foster collaborative working and improve relationships between the trades
- establish common goals
- stabilise the programme and remove uncertainty
- identify and manage potential risks and opportunities
- produce forward plans and identify mobilisation needs
- increase the predictability of activity and project completion
- improve quality and delivery timescales through removing waste.

It brings the whole project team together at an early stage (client, designers, main contractor, subcontractors and specialists) in order to plan the optimum sequence of works. Part of the mechanism of creating this optimum plan is the fostering of effective communication, encouraging each member of the team to input ideas and listen to the ideas of others.

The sequence of works is planned in detail, together with all enabling activities, to create a more predictable plan. These enabling activities include design and information release, procurement and site logistics. This detailed consideration of the needs of the project in advance enables materials and plant deliveries to be controlled so all resources are available when needed, and offsite manufacture to be considered and planned for at an early stage.

Collaborative planning on AIMC4 projects

Collaborative planning was selected as a technique that could benefit key components of the overall project aims, ie quality of delivery to meet the designed performance at a reduced construction cost.

Each of the developer teams held their own initial collaborative planning workshop during August and September 2011. They brought together their site teams, designers, subcontractors and innovative suppliers. Although the overall aims of the project were the same, each developer team had additional targets and goals that they wanted to achieve. These goals were set at the start of the workshop and, throughout the day, each party became committed to achieving them.

For example, one team wanted to challenge themselves to construct the units in half their normal build time, in order to meet the cost targets. Other teams put a greater focus on getting quality right initially, before working on reducing timescales.

The typical workshop starts with an overview of the project and its objectives, and setting out the agenda for the day. The scope of work to be planned out is agreed and each party is allocated a pack of coloured sticky notes. These coloured notes are used to plan out the programme in detail, examining activities day by day. Figure 8 above shows an example of a collaborative plan during the workshop, with all activities shown by trade and in daily detail.

> *The collaborative planning workshops offered a unique opportunity to get all the trades together to discuss the impact they all have on each other. Communication is key and giving all the guys the opportunity afforded by this forum was a great tool in trying to fine-tune the build programme and find the true critical path.*
>
> Sustainability manager

To make this technique most effective, honesty and commitment from all parties is essential. This is encouraged and enabled by bringing the people who are closest to the workface together to plan their own work, meaning the supervisors, foremen and operatives. They alone are able to write their tasks and position them on the programme. Those who are the next step away from the workface, ie the managers and planners, can challenge the sequence and logic, and take an overview of the process. The key technical people are able to add value by providing advice on the effects of programme changes on the performance of elements, and suggesting opportunities for changing designs to improve buildability.

For each individual project, this process was repeated at a later stage to capture lessons and refine the programme for the next phase of works.

Outputs and results

The programme achieved:

- the establishment of shared goals
- an understanding of the AIMC4 project and the importance of maintaining quality with regard to the fabric construction
- in one case, a 16-week standard build programme from foundations to completion was cut to just eight weeks and one day

- better understanding of integrated working and requirements for access, eg the scaffolding lifts and its positioning
- clearer definitions of scope of works, ie avoiding 'grey areas'.

Site-based construction process measurement

Measurement of the construction process is critical to understanding how it is performing. Due to the demands of managing a project, measurement is often not done in sufficient detail to quantify inefficiencies in the process. This means it is difficult to monitor key performance indicators and make targeted improvements to the process.

Where innovative products or processes are being used for the first time, as with the AIMC4 project, undertaking a more detailed level of measurement is essential. This detail enables quantification of specific issues including any implicit money and time waste, allowing targeted improvements to be made. The BRE tools CALIBRE and SMARTAudit were developed to undertake such detailed measurement of labour and resource efficiency.

The specified improvements may reduce costs and construction time, improve predictability and quality or reduce the environmental impact. The effect of this is to increase the viability of innovative products that may, at first, appear more expensive compared with more established products on the market.

A key part of the construction phase of the AIMC4 project was a detailed data collection process. The aim was to understand the construction processes on site in detail and the potential that improvements to them could reduce costs as part of the overall project objectives.

What is CALIBRE?

CALIBRE (Figures 9 and 10) is BRE's site efficiency and productivity applied research measurement tool that diagnoses and quantifies waste in man-hours using activity sampling. It measures onsite efficiency and objectively assesses actual construction productivity and performance on a given project from the start right through to completion. The tool was created using BRE's extensive experience in construction measurement and productivity assessment, developed over the past 30 years. CALIBRE monitoring is simple to do and can be implemented without interfering with the task being undertaken. The process of measurement is carried out by a full-time site observer, often an undergraduate or recent graduate, who can gain a thorough understanding of the construction process whilst collecting valuable data. CALIBRE has four main elements:

1. mapping the construction process
2. identifying the work packages and tasks
3. monitoring the site and factory construction process
4. analysis, reporting and feedback.

Typically, the monitoring and feedback (steps 3 and 4) are undertaken continuously from the moment the first operatives set foot on site to when the last operative leaves the site at the end of each day.

Figure 10: The CALIBRE handheld computer

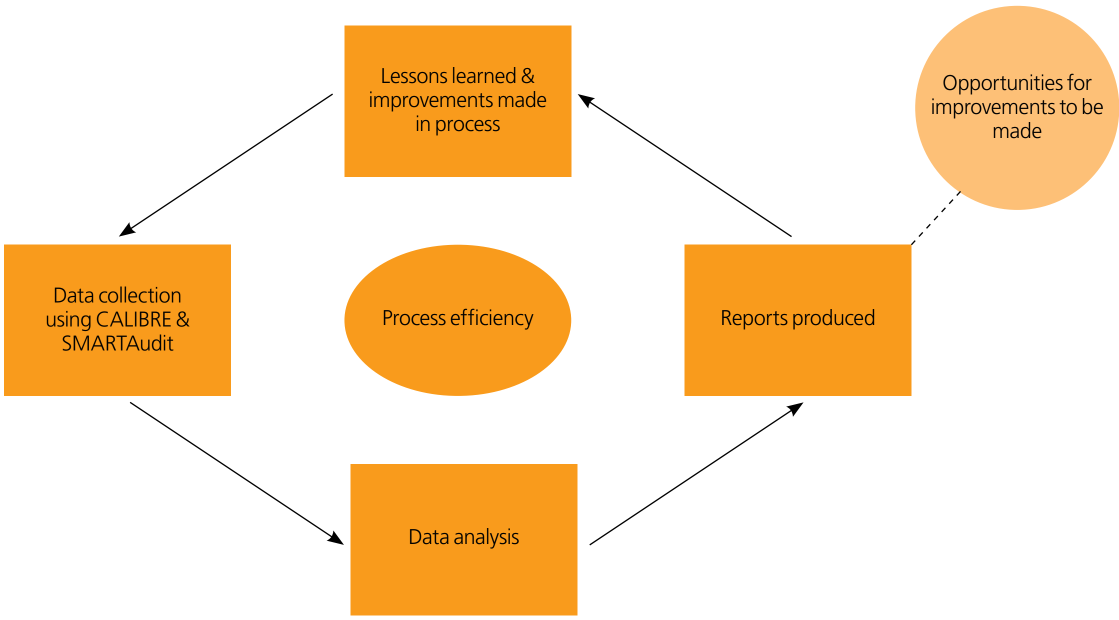


Figure 9: The CALIBRE process

Figure 11: A waste skip on one of the AIMC4 sites

What is SMARTAudit?

SMARTAudit is a unique tool that audits in detail the source, type, amount, cause and cost of waste on site and reports it in a format that is easy to understand. The SMARTAudit measurement process uses the same equipment as CALIBRE to input data about waste and feed it into a database.

The contents of the site skips (Figure 11) are assessed and the volume of each waste product is recorded. The following details are also logged:

- location of the skip on site
- product wasted
- volume of waste (m^3)
- cause of waste
- work package creating the waste
- any notes and photographs.

Data collection on site

Each AIMC4 site had a dedicated full-time site observer who was trained for both CALIBRE and SMARTAudit data collection. They started collecting data on site from day one of the construction process through to completion and the start of the post-construction testing (Figures 12 and 13).

Data was collected in half-hourly 'rounds' of the site, from the point at which work started each morning through to completion of the work each day. This provided detailed data of what resources were required to build the homes, and where the value and waste were in the process.

This data was collated and translated into a series of measures that provided detailed efficiency assessment and comparison between house types, sites and the rest of the industry. A number of these measures and analyses are described below.

Productivity

Man-hours are collected for each plot, element of construction and work package. This measure shows where time was spent during the process for each part of the works or for different methods of construction, and enables comparison between monitored sites. Man-hours per m^2 are also recorded, which can be used for benchmarking and as a measure of productivity.

Figure 12: Measuring the construction process on site

Figure 13: The typical CALIBRE set-up on site

Efficiency

Using the man-hours and activity sampling provided by the CALIBRE data, efficiency can be measured. The time data is categorised into 17 activity codes (Figure 14). For the first time in CALIBRE's history the waste or non-value-added (NVA) time was measured in two ways: the traditional CALIBRE method covers the items shown in the red category; the second method classified 15 of the activities as NVA. The exceptions were categories F (carrying out the prescribed task) and BK (taking a break), which remained statutory. The second method more closely reflects the approach taken within a traditional lean environment, and by BRE CLIP: all the activities other than F are open for challenge, even if in reality they cannot be fully eliminated (eg moving the materials to work area); this generates a more detailed analysis and greater improvements.

NVA time can be analysed per location, element of construction, trade or work package. The metrics can be measured by the number of hours, percentage or the amount of time per m^2.

	Value-added man-hours
C	Cleaning
F	Carrying out the prescribed task
P	Preparation of materials
H2	Handling materials at the workplace
U	Unloading
	Non-value-added man-hours
A	Not seen during observation round
H1	Handling materials from stores to workplace
I	Not working and not at the workplace
N	Not working at the workplace
RT	Making good or correcting
W	Walking around site
	Statutory man-hours
BK	Taking a break
HS	Carrying out work related to health and safety
RO	Inclement weather
	Value-added support man-hours
SU	Supervision
T1	Setting out
T2	Testing and checking

Figure 14: Activity codes for CALIBRE activity sampling

Process issues analysis

The activity sampling data and the site issues sheet provided by the site observer can be analysed and broken down into specific categories to provide assessment of specific value and waste.

Material waste

Analysis is carried out of each specific product causing the waste, where it was generated, and the trade and work package from which it was generated.

The waste data can also be analysed to produce an environmental performance indicator (EPI). An EPI assesses the volume of waste removed from site per 100 m² of floor area constructed. This can be used for benchmarking against other projects.

Post-construction appraisal of the construction process

All of the lean activities undertaken and the data collected on the projects allowed a comprehensive review of the opportunities for cost savings and improvement. The data was analysed for each site and compared across all projects to get an understanding of the priorities for further improvement. The top-level results are illustrated in Figure 15 (Portlethen, Prestonpans and Preston were Stewart Milne sites, Epsom was the Crest Nicholson site and Corby was the Barratt Developments site).

The results are very good, especially for prototype builds. The graph shows how offsite systems require fewer man-hours on site to 'make the building grow', largely because more value-added work has been done in the factory.

The red NVA time can be clearly challenged. Some of this is from one-off or learning errors that will not be repeated. For example, the contractors used at Corby and Epsom had no prior experience with thin-joint mortar systems and made mistakes.

The purple areas represent material preparation and movement. Elements of this will be unavoidable, but it is an area that deserves further investigation.

Added-value support is primarily supervision and would be significantly reduced in future as the trades become familiar with the new techniques.

Figure 16 shows an example of the analysis carried out on the causes of NVA effort, classifying the top issues per trade. This shows that there were a number of key areas to focus on, including:

- Making good, with over 300 hours of making good undertaken in the top proportion of trades. This included:
  - reworking some of the thin-joint walls, which happened at both Corby and Epsom through the use of contractors who had no previous experience with this technique
  - replacing the insulation in the first timber-frame roof cassette (labelled 'offsite roof' in Figure 16) at Portlethen when water penetrated – a problem that was rectified through design improvement for later houses.
- Suggested improvements included further investigation into the snags encountered, a review of the quality control process and setting up standardised work processes for certain trades.
- Overall setting-up for work processes.
- The time spent on handling and preparing materials, clearing up and cleaning was around 1800 hours across the sites; a small number of trades created 80% of all waste.
- Suggested improvements included a 5C housekeeping exercise to look at site set-up, storage locations and workplace efficiency.

Observed issues analysis

Alongside the data analysis of the objective efficiency figures collected by CALIBRE, a second set of data was also analysed. As the observers were collecting activity sampling data, they were also asked to observe the activities and to make notes of the issues encountered and where they observed any form of NVA effort.

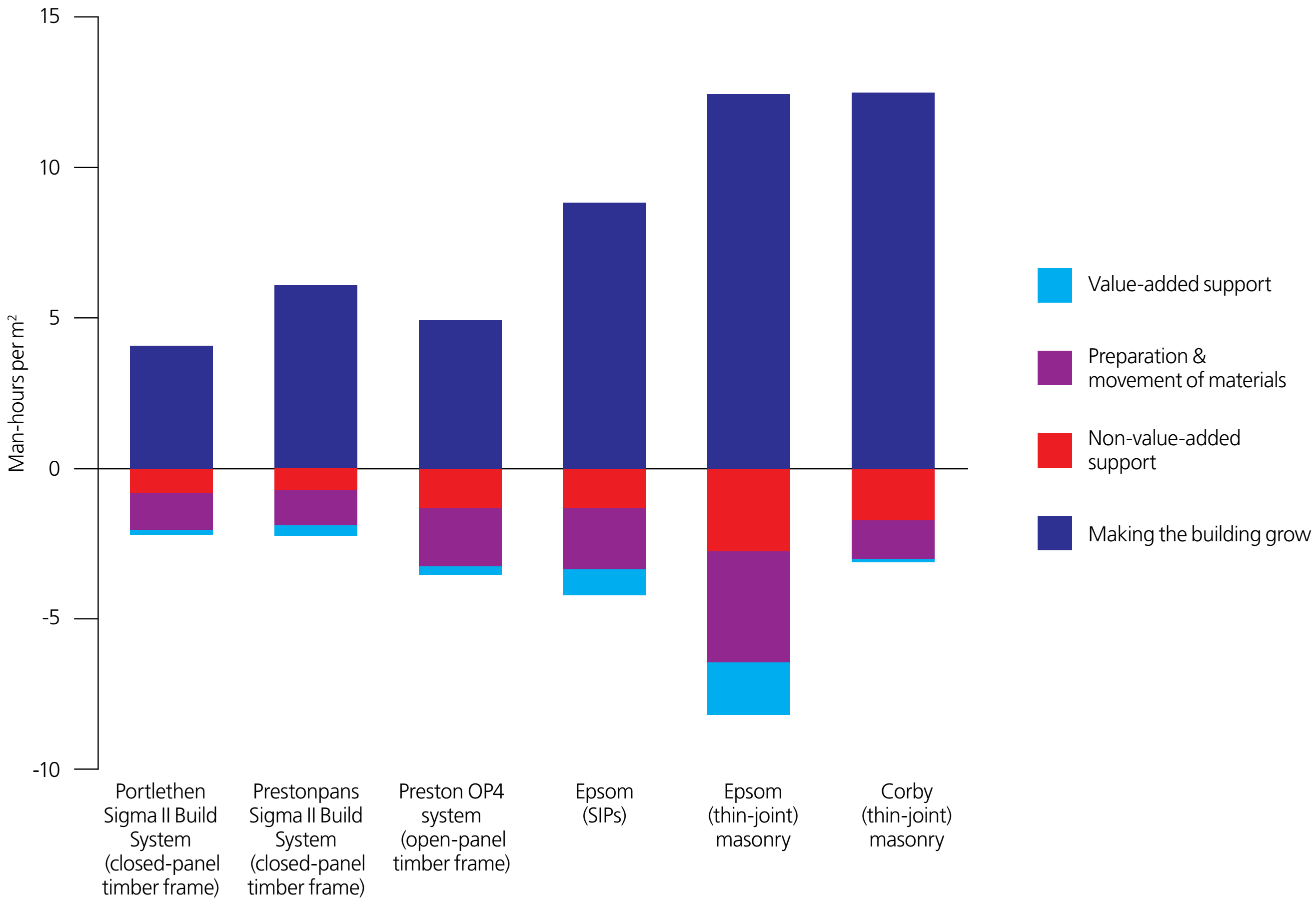


Figure 15: Waste analysis for all AIMC4 sites

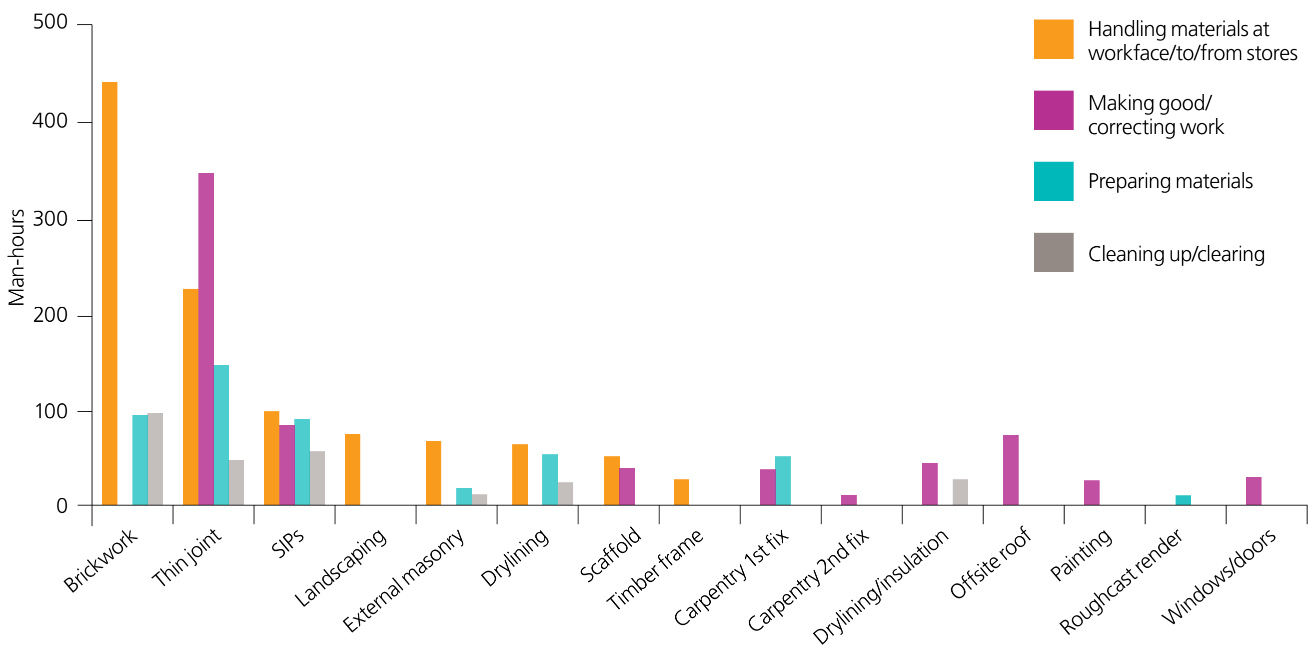


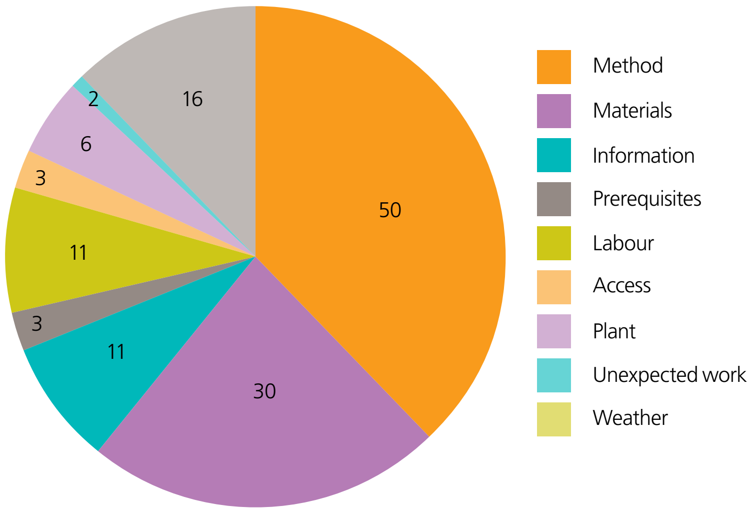
Figure 16: The four leading types of waste for each trade for all AIMC4 sites

These observed issues were analysed and used as a secondary source of potential improvement ideas. An example of the output from the issues analysis is shown in Figure 17.

This analysis typically showed that the main observed wastes were caused by method and material issues. 'Method quality' was identified as a focus area; this is connected to reworking and ties in with the data collected from CALIBRE. 'Method process' was also identified as an issue; this is affected by how the work is planned and controlled. 'Materials quality' was also identified as an issue for some of the sites, which requires feedback to the suppliers and factories about problems in their processes or quality control.

Overall, there were no real distinctions between build types when considering the causes of NVA activity. Each had issues that you would find on any other construction site in the UK, or beyond, around communication of quality requirements and coordination of trade interfaces and the impact of the weather. Further analysis will be required to remove NVA activity and material waste from the process as the new methods of construction become mainstream, but the AIMC4 analysis does help to highlight the areas that will need to be considered.

All issues observed – number of issues recorded



All issues observed – detail

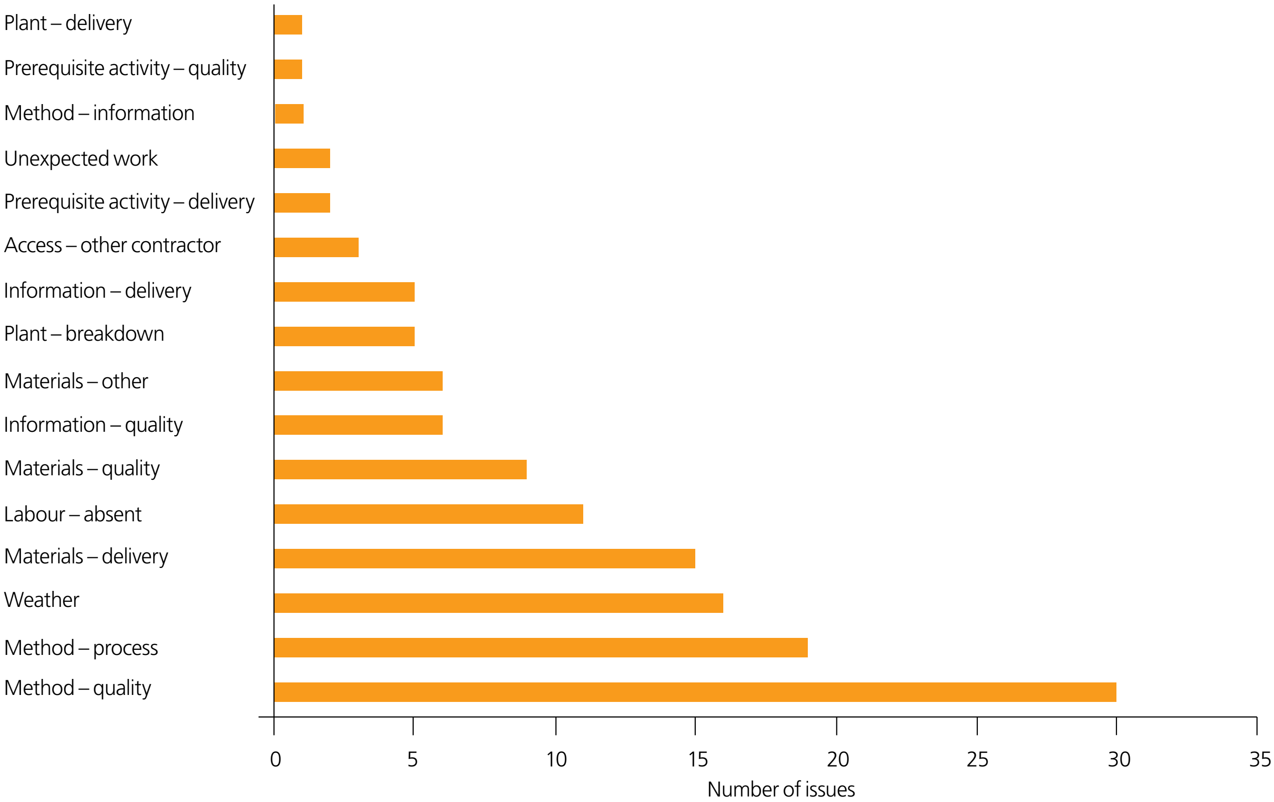


Figure 17: Example graphical output showing number of non-value-added issues

Lessons learned

The bedrock of 'lean' is the concept of the value chain and the requirement to meet the needs of external and internal customers with the minimum of waste (in all its forms). The implementation of a lean approach on the AIMC4 project went beyond theory and Standard Assessment Procedure (SAP)[2, 3] calculations to tackle the practical challenges of building efficiently and minimising costs. It did this through enabling the developers and project teams to identify and neutralise issues before the actual build commenced. One of the major benefits of the application of lean tools and techniques on the AIMC4 project is to provide long-term cost savings by minimising expensive, onsite building time. This was shown at Portlethen, in which the project managed to almost halve the standard build time.

The lean design workshops were an effective way to encourage true collaboration and innovation at the start of the design process. It was possible to achieve this without compromising buildability and project costs.

With collaborative planning, getting everyone in the same room proved to be incredibly powerful. It is important to ensure that the right people are in the room, ie the trade foremen rather than the directors of the individual companies. When this did not happen at first, there was an initial focus on financial issues and some unrealistic ideas on programming, as those people were too far removed from the work. Ideally all trades need to be available for this planning process, which is not always feasible under current practice. Despite this, there were many benefits including:

- clearer common goals and greater collaboration
- significant time savings against standard build times
- discovery and avoidance of risks before work commenced, saving time and cost
- greater opportunities for integrated working
- better definition of work scope and interfaces.

These benefits would have been even greater if applied over an entire site, where there is more opportunity to embed learning. Unfortunately, that was not possible on this project.

CALIBRE and SMARTAudit both provided comprehensive and accurate data that has allowed the developer teams to focus on key areas for improvement as they take the projects forward. It has also allowed benchmarking between the different innovative build methods through using a standard type of home.

Acknowledgements

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