Pre-assembly in Construction (CRISP)

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Pre-assembly in construction

A review of recent and current industry and research initiatives on pre-assembly in construction

Alistair G.F. Gibb

May 2001
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EXECUTIVE SUMMARY

Background

This report was commissioned by the Technologies and Components Task Group of the Construction Research and Innovation Strategy Panel (CRISP).

Its purpose is to identify, illustrate and where possible categorise recent and current initiatives on pre-assembly, particularly within UK construction.

Pre-assembly literally means to ‘assemble-before’. Pre-assembly covers the manufacture and assembly (usually off-site) of buildings or parts of buildings or structures earlier than they would traditionally be constructed on site, and their subsequent installation into their final position. Pre-assembly can be subdivided into four categories:

- Component manufacture and sub-assembly
- Non-volumetric pre-assembly
- Volumetric pre-assembly
- Modular building

Current Research

Almost £5 million has been invested by DETR and EPSRC in research projects that include pre-assembly in construction since 1997. Of this total figure, around £1.1 million covers general innovation which includes pre-assembly, with the remainder concentrating more specifically on pre-assembly. Because of the gearing of the funding, the actual overall value of the research is twice the funded value (ie ~£10 million), with the extra being funded, usually in kind, by the industry partners.

The main schemes that have funded pre-assembly research in the UK construction sector include the EPSRC/DETR Innovative Manufacturing Initiative (Meeting Clients’ Needs through Standardisation) and the DETR Partners in Innovation programme.

Pre-assembly has been well represented in the funding schemes over recent years although it is often disguised as part of broader research projects on innovation and frequently different terms are used instead of pre-assembly. Many projects also combine pre-assembly with standardisation (for more information on this see CRISP report 00/20). Many of the projects reviewed are still in progress and so the outcomes are not yet fully understood. This work has focussed on various different technologies and materials, often led by industry bodies with obvious priorities set by their membership. The research projects reviewed are spread across the industry sectors and involve most of the industry bodies and many universities. There may be an opportunity to check for cross fertilisation between these groups and between the findings of their respective projects.

In addition to their input to government funded projects, industry is doing its own work, but the results are often commercially sensitive and confidential. In particular there has been a recent increase in developments in the residential sector.

Many different university research teams are also involved, with a small number doing most of the work, however, there is little evidence of coordination between teams. This has resulted in a challenge for future work to ensure that it is organised in a holistic manner and takes best advantage of the other work that is already underway.

Furthermore, the deliverables from the funded projects vary considerably, from CDs, videos, high-impact publicity documents to word-processed reports and learned journal papers. Some deliverables have
been disseminated widely and others hardly at all. Websites have been used, but their quality and accessibility again vary widely. Few of the projects have developed the deliverables to the level of practical 'sharp-end' guidance and advice.

The existing DETR and EPSRC websites have not been kept up to date and information on deliverables have often not been added to the data. There appears to be no one place where interested parties can go to obtain information about pre-assembly research.

There is a good opportunity to draw together these deliverables and make them more accessible providing the lead-researchers of the projects are co-operative. Also, future projects could be encouraged to concentrate more strongly on effective dissemination. There are also challenges to take some of the existing work and apply it in a broader sphere, or in a more co-ordinated, strategic manner. The various research networks may be a good way of achieving this, but they have not been going for long enough to evaluate their effectiveness. The deliverables from existing projects are varied in quality and format, with some focussed on dissemination to industrial end-users and others more suitable for academic audiences. Some of the more academic deliverables may be able to be developed into tool kits or other industry-focussed output.

Some international work has been related to the UK situation, but this study has not included a full international review.

**Motivators, facilitators, barriers and implications**

Motivators, facilitators, barriers and implications include: clients and the project team; procurement methods and supply chain relationships; formal/contractual requirements; legislation; changing construction to a manufacturing process; whole life costing, sustainability and waste reduction; people issues, skills and training; new materials and technologies; information and communications technology; pre-assembly; and the measurement of success. There are also some sector-specific issues.

Benefits from pre-assembly are often realised elsewhere in the construction process. Some leading repeat-order clients have started to acknowledge this and moved towards better consideration of pre-assembly, but the one-off clients are harder to involve in this movement. Advisors to the ‘one-off’ client sector appear to be significant barriers to further implementation.

The principle of the important influence of procurement routes and supply-chain relationships for pre-assembly implementation appears to be accepted. But there are many other drivers for procurement routes and there has been much work already completed in this area. By contrast, there has been little work on the link between pre-assembly and formal or contractual requirements, nor on the effect of legislation.

Successful implementation of pre-assembly depends on the industry moving towards a manufacturing process approach and away from an on-site construction approach. Whilst this has been acknowledged, it does not seem to have been worked out in the projects completed to date.

Whole-life costing studies have not been completed for pre-assembly and, although they have been raised, issues of sustainability in pre-assembly have not really been resolved.

People issues have not been covered in much of the existing work except for a project on health and safety and one on skills, education & training. Further opportunities in these areas could be established once these projects have delivered.

There is little evidence of the study of new materials for pre-assembly, although this subject is covered in more detail in another CRISP report recently commissioned.

Because of the way that much of the pre-assembly supply chain is organised, the current applications for ICT are somewhat limited. This should be an area of further opportunity, but only if the supply chain moves to embrace ICT more fully.

Existing methods of measuring project success are not developed sufficiently to adequately evaluate the benefits of pre-assembly, but a number of existing projects are currently working in this area.
The research on pre-assembly is more or less evenly split between general (no specific sector) (36%), the residential sector (39%), and the remainder major building and civil engineering with a small amount covering maintenance, repair and refurbishment. There appears to be little work aiming to co-ordinate this work or apply lessons learnt in one sector to the challenges of another sector.

Conclusions

There is much existing research work looking at pre-assembly, although it is often combined with broader subjects. Much of the work is not co-ordinated well and benefits may be gained from further efforts in this area. Further work should be encouraged especially where it effectively engages the whole supply chain and is targeted on producing end-user guidance.
CRISP Consultancy Commission – 00/19

A review of recent and current industry and research initiatives on pre-assembly in construction

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A review of recent and current industry and research initiatives on pre-assembly in construction

1 INTRODUCTION

1.1 Background to this report

This report is the result of a commission from the Construction Research and Innovation Strategy Panel (CRISP) through their Technologies and Components Task Group.

Pre-assembly is seen as one of the tenets of improving construction in the 21st century by its inclusion in the UK Government sponsored report Re-thinking Construction (Egan 1998). At the Movement for Innovation conference in May 2000, Construction Minister Nick Raynsford stressed that "a much greater emphasis on off-site assembly was one of the key ingredients to changing the construction culture to retain and recruit talent and at the same time deliver improvements in performance required by increasingly demanding clients" (Raynsford 2000).

1.2 Aims and objectives

The purpose of this report is to identify, illustrate and where possible categorise recent and current initiatives relating to off-site fabrication (pre-assembly), particularly directed at the UK construction sector. International and non-construction initiatives are identified where possible. However, it is important to note that this is a review of research initiatives rather than a full review of industry practice and, in the main, considers UK government funded research into pre-assembly.

1.3 Report scope and structure

First, the report defines pre-assembly. Then the nature of pre-assembly research is explained by looking at the primary UK research funding schemes, reviewing funded projects and their deliverables. EU and other internationally funded projects have not been reviewed. Where possible industry commissioned research has been reviewed, mainly through patent search and professional journal article review. However, it is acknowledged that this approach is limited as much industry research is confidential.

Various motivators and barriers to the increased use of pre-assembly are then discussed along with implications and facilitators. Best practice examples are presented and work outside the UK is briefly introduced. Much of the text is supported by a series of appendices that can be found at the end of the report.

2 PRE-ASSEMBLY

2.1 Definitions

Pre-assembly, prefabrication, modularisation, system building, and industrialised building are all terms in common use at various times over the last century. The terms are often interchanged and their precise definition depends almost entirely on the previous experience of the user. This use and misuse of terms may appear trivial, but it can cause confusion and misunderstanding. It is not the purpose of this report to debate the rights and wrongs of these terms. Nevertheless, the report’s preferred term is pre-assembly which literally means to ‘assemble-before’. Pre-assembly covers the manufacture and assembly (usually off-site) of buildings or parts of buildings or structures earlier than they would traditionally be constructed on site, and their subsequent installation into their final position. Pre-assembly can be sub-divided into four categories (Figure 1):
• Modular Building
• Volumetric Pre-assembly
• Non-volumetric Pre-assembly
• Component Manufacture and Sub-assembly

Figure 1  Categorisation of pre-assembly

Other terms are still much in use, and each has it's own adherents, however some of the arguments for not using them are as follows:
Prefabrication  Has negative connotations from the ‘prefab’ age.
System building May be a very accurate term, but many of the applications are not actually part of a system at all.
Industrialised building: A useful term but again conjures up the thoughts of rows and rows of identical (and boring) buildings.
Modularisation: Implies an element of modular co-ordination, which again is often not the case in contemporary applications.

This report covers pre-assembly and it’s application to the construction industry, including civil engineering, engineering construction (petro-chemical/power generation); major building; residential building; maintenance, repair and refurbishment.

2.2 Innovation and Standardisation

Many of the research projects reviewed were on the subject of innovation. Two of the main research funding schemes are Partners in Innovation and the Innovative Manufacturing Initiative. Many of these projects include pre-assembly along with a number of other innovations, both in process and technology. This report concentrates on pre-assembly in particular and has not sought to review the
broader subject of innovation. A number of CRISP reports have already been produced on this subject and these are listed in Appendix 1.

Similarly, pre-assembly is often linked to standardisation and occasionally the terms are even interchanged. However, not all pre-assemblies are standardised and many standard solutions do not involve pre-assembly. The CRISP Task Force has also commissioned a review of research initiatives in the area of standardisation and customisation. Therefore, these issues are not specifically dealt with in this report.

3 NATURE OF PRE-ASSEMBLY RESEARCH

3.1 Primary research funding schemes

3.1.1 Innovative Manufacturing Initiative (IMI)
EPSRC/DETR IMI LINK (Meeting Client's Needs through Standardisation)

The Innovative Manufacturing Initiative forms part of EPSRC's construction as a manufacturing process theme. Most of the projects are joint funded with DETR under the Link scheme. EPSRC argue that the construction industry in the UK is undergoing a period of intense debate and change. Learned reports have called for a fundamental change in the culture of the industry to assist in delivering significant improvements in the performance of the industry. One building block is for the industry to invest in research and development which seeks to apply some of the experience and lessons from the manufacturing sector. The aim is to seek how the culture and technology of the industry can, with appropriate modification, be more aligned with the precepts of manufacturing processes.

IMI's main objective is to stimulate and fund jointly with industry collaborative projects between industry and academia which impact upon the key success factors identified in the construction sector:

- to increase value for money for clients through better identification of clients needs and improved management of the construction process;
- to reduce costs, increase competitiveness and shorten project delivery times through enhanced technology and business processes;
- to improve quality and productivity throughout the whole construction process to deliver completed projects which satisfy client needs;
- to support cultural change in the industry towards continuous improvement.

The construction as a manufacturing process sector programme was launched in 1995. A broad research framework was established which has been refined in 1997 taking account of the views of industry as represented by CRISP. From the first three calls 25 projects have been funded with a total research value of £6M. Public funds have contributed £3.4M to this total, the balance being input from industry. The responses to two further calls are currently being processed. In reviewing the portfolio account is taken of complementary projects which obtain their public funding from different sources. 44 projects fall within the CMP theme.

Within IMI construction, the theme meeting clients needs through standardisation (mcns) has particularly focussed on the standardisation and pre-assembly area. Most of these projects have been joint funded by DETR on the Link scheme. However, EPSRC have also individually funded pilot studies and networks in the area.

The IDAC Link scheme (Integrating Design and Construction) has supported work which includes, but is not limited to, standardisation of the design and construction process. EPSRC have funded 6 IDAC link projects in the current phase with a cost to EPSRC of £813k.

3.1.2 Partners in Innovation (PII)

Partners in Innovation (PII) programme (was PIT – Partners in Technology)

Partners in Innovation (PII) is a DETR scheme which sponsors collaborative research in partnership with industry, academia and government. The scheme is implemented through a challenge-based competitive bidding process. It provides up to half the cost of construction-related innovation and technology transfer projects and is open to all UK construction firms, industry bodies, institutions, research and technology organisations and universities.
PII have funded a number of projects in the area of standardisation and pre-assembly as has the previous programme, Partners in Technology (PiT).

### 3.1.3 EPSRC and other open schemes

The EPSRC’s overall mission is:
- to promote and support, by any means, high quality basic, strategic and applied research and related postgraduate training in engineering and the physical sciences;
- to advance knowledge and technology, and provide trained engineers and scientists, to meet the needs of users and beneficiaries thereby contributing to the economic competitiveness of the United Kingdom and the quality of life of its citizens; and
- to provide advice, disseminate knowledge, and promote public understanding in the fields of engineering and the physical sciences.

There are four main programmes that fund construction research:

<table>
<thead>
<tr>
<th>Programme Name</th>
<th>Number of Grants</th>
<th>£ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering for Infrastructure &amp; The Environment</td>
<td>606</td>
<td>98,715,429</td>
</tr>
<tr>
<td>Engineering for Manufacturing</td>
<td>577</td>
<td>123,335,883</td>
</tr>
<tr>
<td>General Engineering</td>
<td>1284</td>
<td>160,139,351</td>
</tr>
<tr>
<td>Materials Programme</td>
<td>918</td>
<td>149,046,273</td>
</tr>
</tbody>
</table>

However, most of the research in standardisation and pre-assembly is funded through one of the managed schemes such as IMI rather than by these open calls.

### 3.2 Review of funded research on pre-assembly

Details of DETR and EPSRC funded research projects on pre-assembly are provided in the Appendices as follows:

- Appendix 2 Summary of funded research on pre-assembly
- Appendix 3 Background details of EPSRC-funded research on pre-assembly
- Appendix 4 Background details of DETR-funded research on pre-assembly

The base data for these appendices was taken from the EPSRC and DETR websites. Then lead researchers were contacted to verify the information and provide further details.

Appendix 2 lists all the funded research projects in the area, listed in alphabetical order of the titles. Also listed are the lead researcher, funded value range, completion date, funders and a classification of the content. Appendices 3 and 4 provide further information on the research projects, listed under project reference number.

Almost £5 million has been invested by DETR and EPSRC in research projects that include pre-assembly in construction since 1997. Of this total figure, around £1.1 million covers general innovation which includes pre-assembly, with the remainder concentrating more specifically on pre-assembly. Because of the gearing of the funding, the actual overall value of the research is twice the funded value (ie ~£10 million), with the extra being funded, usually in kind, by the industry partners.

Figure 2 shows the breakdown of pre-assembly research funding by construction sector. Around two thirds is of a general nature and not specifically aligned to a particular industry sector. The largest sector-specific area is timber (15%), with mechanical and electrical services at 10%. Concrete, steel and brickwork make up the balance with between 3 and 4% each. There is no funded work on cladding pre-assembly nor on foundations. These percentages largely reflect the influence of the various sector representative bodies as described further in section 4.4.
3.3 Industry research

3.3.1 Company specific research

It should be remembered that much of the government-funded research in this area is also funded by industry (usually 50% for Link projects and more for PII). Therefore, the funded research provides an indication of the aims and objectives of industry. However, because of the public dissemination emphasis of these projects, they only tend to cover the more general research topics. Many of them do not seem to lead to patentable exploitation.

However, there are notable exceptions to this, such as the spin-off company to be set up by Westbury as an outcome of the market-led homebuilding as a manufacturing process project.

Privately funded research is hard to review in a study such as this, because many of the deliverables remain confidential. For instance, NHS Estates has completed a number of research projects on standardisation, but the project reports are confidential and the results have only been presented in summary at public workshops. Several companies are releasing information from their research, often at groups such as the Movement for Innovation clusters.

Individual companies are undertaking research, either on their own or by private arrangements with academia or consultants. Some of this results in patentable inventions and these are listed in Appendix 5. These were obtained by searching the Patents website. This records inventions that have been patented in the UK or in the US. It gives the country of origin, title and inventor (or organisation). The key words that were used for this search were construction/building/civil engineering/housing/residential along with pre-assembly**/prefab**/modul**/panel/system/pod/manufactur**. It is the author’s view that considerably more patents covering pre-assembly may exist but are not evident because the appropriate terms may not appear in the title. It is significant that, after a large number of patents on pre-assembly in the 1960’s, there were almost none for more than 20 years and even now their numbers are few. Furthermore, many innovations using pre-assembly are not actually suitable for patenting but would be better described as registered designs (for instance McDonald’s applications of Yorkon and Britspace modular units.

The residential sector is one of the most buoyant in terms of recent pre-assembly applications as the following shows:

Space 4 Westbury Homes
Beazer Tee U Tec
Elliott Sunley Turiff
Britspace Guinness Trust and Wimpey

New house prefabrication factory using panel construction techniques
Timber frame house development
Fully fitted volumetric steel house trials
House trials
The Housing Forum is leading much of this drive and has set up an off-site fabrication and standardisation working group. The National House Builders Council (NHBC) has an initiative for pre-assembled buildings with an environmental focus called ‘touching the earth lightly.’

There are a number of leading industry organisations that are encouraging increased use of pre-assembly. For example, Bovis Homes released the following figures in their year 2000 annual results:

<table>
<thead>
<tr>
<th>Notional usage 2000 (%)</th>
<th>Target notional usage 2001 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory pre-finished, pre glazed windows</td>
<td>31</td>
</tr>
<tr>
<td>Factory pre-finished soffits, fascias, barge boards</td>
<td>30</td>
</tr>
<tr>
<td>Factory pre-assembled, pre-finished GRP porches</td>
<td>97</td>
</tr>
<tr>
<td>Factory pre-assembled, pre-finished GRP dormers</td>
<td>2</td>
</tr>
<tr>
<td>Factory assembled pre-glazed external steel doorsets</td>
<td>14</td>
</tr>
<tr>
<td>Factory assembled internal doorsets</td>
<td>0</td>
</tr>
<tr>
<td>Factory assembled pre-glazed cassette doorsets</td>
<td>4</td>
</tr>
<tr>
<td>Factory assembled pre-glazed external feature doorsets</td>
<td>58</td>
</tr>
<tr>
<td>Factory pre-finished garage doors</td>
<td>100</td>
</tr>
<tr>
<td>Factory pre-fabricated engineered joist sets</td>
<td>0</td>
</tr>
<tr>
<td>Factory finished radiators</td>
<td>100</td>
</tr>
<tr>
<td>Factory pre-assembled stair parts/balusters</td>
<td>57</td>
</tr>
<tr>
<td>New technology snap fit plumbing</td>
<td>48</td>
</tr>
<tr>
<td>Factory pre-plumbed thermal store cylinders</td>
<td>61</td>
</tr>
</tbody>
</table>

3.3.2 Industry bodies’ research

Some industry bodies have been very successful at obtaining research funds in the area, in particular BSRIA (Building Services Research & Information Association), TRADA (Timber Research And Development Association), SCI (Steel Construction Institute) and CIRIA (Construction Industry Research and Information Association). These bodies have often been able to harness industry support on particular issues and target the specific foci of the government-funded research funding themes to supplement funding from their members. Most of them concentrate on technologies and techniques specific to their membership (e.g. BSRIA, TRADA & SCI) and, as a result, the findings may not be directly applicable to other sectors, or sometimes the broader lessons may just not be identified. There are some examples of these organisations working together, for instance the BRE-led advanced off-site production of steel/timber building systems involving both SCI and TRADA. Furthermore, co-construct is an initiative to provide a common outlet for the various organisations under one umbrella. CIRIA’s work has generally been less specific with more generic applications.

3.3.3 Building Services Research and Information Association (BSRIA)

BSRIA is the association for building services research, assisting the building services industry and its clients to improve the quality of its products and services, the efficiency of their provision and the effectiveness of their operation.

BSRIA organise their research activity under six headings. Most of the pre-assembly work falls under process and productivity or best practice and management as follows:
4. Thermal Comfort in Buildings
5. Process and Productivity

- Innovative M&E installation techniques and procedures
- Uptake of productivity improvements - demonstration of best practice cost-effective solutions
- Building services best practice initiative
6. Best Practice and Management

- Best practice clubs for innovative strategies in building services
- Building services consultancy market (CIBSE)
- Building services best practice initiative
- Building services regional research task force
- Partnering toolkit: maximising the benefits with specialist contractors

BSRIA have been one of the leading organisations researching in the sector and have developed a particular approach towards measuring the success of the implementation of pre-assembly and other innovations.

3.3.4 Timber Research and Development Association (TRADA)

TRADA is a centre of excellence on the specification and use of timber and wood products. TRADA’s mission is to build markets for timber and wood-based products and increase sales in the UK. TRADA maintains active programmes of research and information.

The TRADA co-funded research programme is designed to support their objective of developing markets for timber and wood products, as well as providing material for the information programme. Current and recently completed projects that impact on pre-assembly include:

*Timber frame housing and construction*
- Re-engineering timber frame: A demonstration project
- Factory prefabrication and construction: A demonstration project
- The Timber Dwelling

*Engineered timber and components (structural uses of timber)*
- Communicating timber connection design – an IT toolbox for professionals
- Adhesives systems for timber structures- Performance classification and code user selection guidance
- Shear - Extending markets for wood based panels by developing a better understanding of shear test methods and board shear properties
- Local reinforcement of timber structural elements with composite materials

*Timber supply chain etc. (non-constructional uses, statistics, e-commerce, etc.)*
- The timber industry – implementation of recommendations to increase competitiveness
- UK timber products to improve competitiveness – a feasibility study

3.3.5 Steel Construction Institute (SCI)

SCI is a research and technical organisation supporting the use of steel in construction. Their objective is to develop and promote the effective use of steel in construction.

SCI’s research and development activities cover many aspects of steel construction including multi-storey construction, industrial buildings, light gauge steel framing systems, stainless steel, fire engineering, bridge and civil engineering, offshore and hazard engineering, development of
structural analysis systems, environmental engineering and information technology. The results generated by these projects are fed back to SCI members. Information is also disseminated more widely, both nationally and internationally, by publications and courses based on the research findings.

Publications based on pre-assembly research include the following:
- Guidance notes on best practice in steel bridge construction - [P185] December 2000
- Steel Package Water and Waste Water Treatment Units [P254] November 2000
- Composite slabs and beams using steel decking: Best Practice for design and construction [P300] - September 2000
- Building design using cold formed steel sections: Durability of light steel framing in residential building [P262] - August 2000
- Case studies on light steel framing (Second series - B)[P176/B] - May 2000
- Pressures for change in the construction steelwork industry - solutions and future scenarios [P293] - February 2000
- Modular construction using light steel framing - An architect's guide - Nov 1999

3.3.6 Reinforced Concrete Council (RCC)\textsuperscript{vii}

The RCC undertakes research and development in a variety of techniques and applications related to reinforced concrete frames. The RCC is also closely associated with the British Precast Concrete Federation (BPCF).

\begin{table}[h!]
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\begin{tabular}{|c|}
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Topics already investigated include: large area pours, comparative costs, economic floor designs and reinforcement methods, computerised design, frame specification, and tilt-up construction. It also co-funded the \textit{European Concrete Building} at Cardington, participating in research into rationalised reinforcement, IT for the more efficient supply of reinforcement, early striking of formwork, and design and construction efficiency issues. Three projects particularly dealing with pre-assembly are described as follows:

\textit{Tilt-up Concrete Construction}
Following a survey of world best practice and UK requirements, the RCC has published \textit{Tilt-up concrete buildings: Design and construction guide}, covering benefits, economics, design, construction, and examples. This, and the recently formed Tilt-up Construction Group, are aimed at encouraging the use of tilt-up construction in the low-rise retail, commercial and industrial sectors.

\textit{Rationalised Reinforcement}
The primary objective of this project is to reduce the costs of flat slab construction by disseminating meaningful guidance on the rationalisation of reinforcement. Within the construction industry there are many different views about what constitutes the most economic way of reinforcing concrete. This is especially true of reinforced concrete flat slabs where strict adherence to codes can give 60 reinforcement arrangements. Comparative studies were proposed to evaluate the benefits of rationalising reinforcement sizes and spacings, using bespoke prefabricated mats or fabric, and using different methods of punching shear provision. The work involved producing rationalised
and prefabricated layouts of reinforcement to be used in the in-situ building of the *European Concrete Building Project*, and measuring and disseminating the time/cost benefits. The reduction of complexity and the benefits of increased rationalisation and prefabrication will improve the quality and competitiveness of flat slabs and will have important spin-off benefits for other areas of the construction industry.

**Hybrid Concrete Construction**

Hybrid forms of concrete construction combine all the benefits of precasting (e.g. quality, form, finish, colour, speed, accuracy, prestressing), with all the benefits of in-situ construction (e.g. economy, flexibility, mouldability, thermal mass, continuity, durability and robustness). This DETR PiT sponsored project aimed to identify the most advantageous systems (i.e. the best standard components for customised solutions) and quantify their potential benefits. An understanding of customer requirements, the design and construction business processes, and cultural and technical barriers will allow industry to develop the components necessary to exploit hybrid forms of construction. The research to date has been guided by a widely based Steering Group and active support has have been received from many individual companies.

3.3.7 Construction Industry Research and Information Association (CIRIA)

CIRIA is a UK research association concerned with improving the performance of all involved with construction and the environment. CIRIA works with industry to develop and implement best practice, leading to better performance. Contractors, clients, designers, regulators, financiers and government are all regularly involved in CIRIA’s programme of activities.

CIRIA produces best practice guidance in the form of technical reports, strategic guides, training packs, CD-ROMs and leaflets. These documents address key aspects of business practices such as legislation and regulation, training, management and economics. CIRIA also specialises in promoting and implementing best practice guidance to help industry practitioners improve their performance. Key implementation initiatives include networks such as the CPN (Construction Productivity Network); training events; in-house implementation services; and supply chain seminars. New initiatives include the use of the Web and intranets to further improve company performance.

CIRIA’s work on pre-assembly has mainly been undertaken under their building and construction technology theme along with the following:

- building design and buildability
- building technology
- concrete and structures
- materials
- materials technology
- standardisation and pre-assembly

3.4 Researchers and Research Bodies

Figure 3 shows the lead research bodies involved in funded projects in the overall standardisation and pre-assembly area. Some of these projects are just pre-assembly, some just standardisation, some both and some more general innovation projects which still have an impact on S&P. Figure 4 shows the teams that are focussing on pre-assembly research. The general innovation work is still included, but projects specifically dealing with standardisation alone have been left out. Where projects have more than one research partner, the funds have been divided between the parties (e.g. CIRIA and Loughborough). However, in-kind or secondary involvement of industry or academia is not shown.

For details of the specific projects see Appendices 2, 3 and 4. The purpose of the charts is to show the breadth of involvement in the area, both by academia and industry bodies, and to identify the lead organisations. However, because of the nature of the data, precise comparison between organisations should not be made.

One implication that can be drawn from the charts is that there is much work that is continuing, largely in an uncoordinated manner. In other words the individual projects may be being managed efficiently but they may not be relating effectively to the pre-assembly work as a whole.
There are several examples of major collaborations and of course the various networks will aid this interaction and synergy. Nevertheless, there is a strong need for more integration of research projects and their outputs.

Warwick University’s projects are a series on *market-led homebuilding as a manufacturing process* with the latest project funded to £492k. The Building Research Establishment (BRE) has won a considerable number of PI projects as well as some direct government funding under a framework agreement linked to their privatisation. Loughborough’s work includes projects shared with CIRIA. TRADA and BSRIA are the leading industry organisations researching in the area (timber and building services respectively). There are very few individual industry companies responsible for projects. Architect Brookes Stacey Randall, Buro Happold and Celcon are notable exceptions. However, many individual companies are involved in the projects, providing in-kind and cash support.
Figure 3  Researchers involved in funded projects in the standardisation and pre-assembly area (by funded value)

Figure 4  Researchers working on funded pre-assembly research projects
3.5 Review of deliverables from funded research on pre-assembly

Appendices 3 and 4 show the deliverables from the funded projects taken from the DETR and EPSRC websites. Where possible, these deliverables were then reviewed to form the basis for this section of the report. Where the appendix shows ‘not known’ for deliverables, the website has no record and the participants have failed to respond to the reviewer’s contact. It should be noted that many of the projects are still underway and as such the deliverables may be limited at present.

Most completed projects have produced formal reports, although the style, format and availability varies considerably. Some projects produce high quality, full colour, publisher standard reports, often with 4 or 8 page high-impact summary documents, clearly aimed at getting across the main learning points of the project. These projects appear to take particular note of the need for effective dissemination outside of the project partners. Often, it is the projects involving the industry sector bodies such as BSRIA or TRADA that take this approach for their deliverables. Frequently the summary documents are distributed free of charge, whereas the main reports are sold at ‘market’ prices. As such, the summary documents act as something of a publicity shot for the main documents. A recent development has been the one-page, full colour fact-sheet leaflet which has become very popular with groups such as M4I and CBPP.

Many of the project reports are of a good quality, word-processed standard. They list the project aims, objectives, methodology, conclusions and recommendations. However, these projects stop short of the sort of publicity summary documents mentioned above. It is unclear how these reports are disseminated. It would appear that the project teams’ use their own networks to disseminate them free of charge and then print more copies to send to others who make contact to ask for more information.

There are a few projects which are clearly focussed on the tool kit / practical guidance approach. Of particular note is the CIRIA guide to standardisation and pre-assembly which offers tools on opportunities, strategy and measurement. These are check-lists, decision trees and management flow-charts. Also BSRIA’s output from projects like innovative M&E installations which has produced a series of one page data sheets covering: why you should use this system; key project details; total installed cost and installation time comparison.

RCC’s tilt-up construction have produced a video as their main deliverable (now available as a CD). CD format is becoming more popular, for instance, CIRIA’s revised guide and tool kit will now be in interactive CD format.

Hard copy newsletters, although still used, appear to be gradually superseded by websites. For the industry bodies the websites are easily accessible through the organisation’s main home page. But for many academic led projects access to the sites is less transparent, usually requiring prior knowledge of the web address. Furthermore, the content of the sites is very varied. The better sites offer hot links to participants, down-loadable project reports, discussion forums etc. Others merely list the basic information such as aims, objectives and project summary. Sadly, some websites had not been kept up to date. Another important point is that websites are somewhat passive dissemination outlets, in that people must choose to visit them and there is some indication that proactive measures such as mail-shots of newsletters may still be an effective way of disseminating information, perhaps best used acting as a pointer to more information available on the website.

Many projects have been featured in professional journal articles, again, especially those involving industry bodies. Some of these are in industry sector journals, others in research publications (Research Focus etc) and others in general construction journals (Building, NCE etc). However, the general journals tend to favour the more headline grabbing projects.

Learned journal papers feature highly, especially in the academic-led projects. This is not surprising as this is one of the measures that is taken in the HEI research selectivity exercise for the success of a project. These journal papers often lag the completion of the project by several months or even years, mainly due to the long periods for refereeing and then awaiting publication. Academic conference papers are also favoured, often for disseminating interim results. There is some evidence of industry workshops and seminars being used for dissemination, although these are often not recorded formally.
Several of the projects are actually networks and as such are disseminating research and contributing to the knowledge exchange as part of the process. Several correspondents have commented that this situation is mirrored across other construction research sectors.

There may be the opportunity to pull together some of the projects that have only taken their deliverables up to the formal report stage and produce some practical tool kit guidance. However, this would require the full co-operation of the lead researchers of the various projects. Many academics are not very experienced at producing such focussed guidance so any efforts to this end should ensure that the deliverables really will be suitable for the needs of the industry.

4 MOTIVATORS, FACILITATORS, BARRIERS AND IMPLICATIONS

4.1 Clients and customers

4.1.1 Client types

Clients and customers can be both motivators and barriers to pre-assembly implementation. One of the key principles of pre-assembly is that the benefits are often realised elsewhere in the construction process. In other words the actual elements being pre-assembled may be more expensive than the site assembled alternative. However, issues such as reduced site labour, less disruption and better quality control can produce savings that outweigh the additional first cost of the items. What this means is that the client and their advisors need to recognise this aspect in order to promote the increased use of pre-assembly. Hence, it is often the repeat-order clients that seem to be leading the field.

This creates a dilemma for the industry as the bulk of construction work is commissioned by one-off clients and their advisors, thus creating a barrier to increased use of pre-assembly. In the latest PII round, Loughborough and CIRIA have won a project to adapt their clients’ guide to the needs of one-off clients. This project is due to start in January 2002.

4.1.2 Leading clients

As explained in section 4.1.1, it tends to be the repeat-order clients who are leading the way in optimising pre-assembly. One of the main organisations involved is the Construction Round Table with members such as BAA and McDonalds Restaurants. Housing trust Peabody has been a strong supporter of pre-assembly in its Murray Grove and Raines Dairy projects. Their motivation is a belief that pre-assembly will improve the long-term quality and performance of their properties which is their main goal. In addition, they claim reduced disruption of occupants of neighbouring residences (many of which they own).

The other leading clients have been the residential client/developer/builders although the residential sector seem split on the pros and cons of pre-assembly with some espousing to full modular building, others working with panellised systems and yet others preferring traditional on-site construction methods.

4.2 Project team

There are some good examples where project teams have stimulated and encouraged the increased use of pre-assembly. However, it is important that the whole project team must be committed for effective implementation and this is made easier in vertically integrated teams. This is also important as benefits from pre-assembly are invariably realised elsewhere in the project and traditional element-specific consideration of project costs tends to miss such benefits.

There does not seem to be much leadership for pre-assembly in design organisations. Many architects appear to reject pre-assembly out of hand, often referring to the limitations of previous generation’s applications. Many current construction processes do not encourage more innovation from designers. There are notable exceptions with architects working with developers like Peabody, however, generally the RIBA and its members remain a major barrier to the increased use of pre-assembly. Compounding this situation, some of the applications, especially of modular building, appear to lack good aesthetic design, which only goes to support the majority opinion. Sadly, despite much publicity, good examples such as Peabody’s Murray Grove often go unnoticed by much of the
design profession. Few architectural practices are directly involved in the pre-assembly research projects reviewed.

4.3 Procurement methods and supply chain relationships

Procurement methods will affect the way in which the expertise in the supply chain is released to benefit the project and this is particularly true for pre-assembly.

Historically, the supply chain has been neither a driver nor a barrier to pre-assembly. They have merely done what the client asked. More recently, through partnering, parts of the supply chain have been empowered and some are explaining the benefits of pre-assembly to enlightened clients and are showing willing to share the reduced costs and reduced risks. However, the construction supply chain is very ad-hoc and some will still sell to the highest bidder whatever the highest bidder wants.

There is some evidence, through patents, that some suppliers are developing new pre-assembly systems and techniques.

There is a real challenge set by the fact that much of the supply chain is made up of small to medium sized enterprises (SMEs). SMEs find it hard to invest in new technologies as they rarely see the benefits early enough to recoup their initial outlay. Some SMEs are grouping together to address these issues. Nevertheless, the SMEs are still very under-represented in the research sector as a whole, including pre-assembly research.

Several of the reviewed research projects include consideration of supply chain issues. For example, the CIRIA projects have stressed the importance of employing procurement methods that enable early access to effective manufacturing and construction expertise. Also, Celcon’s project on factors affecting the use of pre-fabricated masonry systems identifies production and use of information in the supply chain as a key issue.

Loughborough’s IMMPREST project is measuring value as it occurs across the supply chain and identifying how project stakeholders can benefit from this added value. Both Salford’s network for the integration of design and construction and Cranfield’s lean construction network are dealing with supply chain innovation. Furthermore, Salford are at the heart of the work on partnering and process protocol.

It is hard to see much more specific research in this area. The problem is that the principle of early construction and manufacturing involvement is accepted as a major benefit and procurement routes such as partnering are particularly good at obtaining this input. However, there are many other issues that affect the choice of procurement route and the industry is divided as to their relative merits. Nevertheless, the key to unlocking more efficiency certainly lies with the supply chain and therefore supply chain relationships are likely to continue to be featured in pre-assembly research.

4.4 Formal/contractual requirements

There is some evidence of standard sub-contract procedures can act as de-motivators for innovation including pre-assembly. However, there has been no real investigation in this area and so this provides a considerable opportunity for further research.

4.5 Legislation

There is no research evidence of legislation being a main driver or barrier to pre-assembly. There is some anecdotal suggestion that the Building Regulations may work against innovative solutions such as pre-assembly. However, the author has not been able to identify any specific evidence on this.

This subject has been considered by CRISP under the broader heading of innovation (Report 99/12 How can regulations promote construction innovation?).
4.6 Construction process >> manufacturing process

One of the limitations causing a lack of realisation of benefits from pre-assembly has been the failure of the industry to change the construction process to a manufacturing process. Ad hoc application of pre-assembly has brought some benefits but these have often been lost in the overall project review. The key manufacturing process issues include the timing of decisions and the acceptance of a ‘product’ rather than a bespoke ‘build from scratch’ approach. Process issues are dealt with in more detail in the companion CRISP report into standardisation.

Developing a manufacturing process is one of the priorities in the CIRIA projects and once again the networks are covering process issues. The Warwick projects looking at homebuilding as a manufacturing process are seeking to develop a process engineering information system to help create such a culture, and deal effectively with product variants to support mass customisation. Warwick claim that rapid product configuration to customer specification and consistency of the build process will require an increasing use of pre-assembled parts. The supply lead times for fixtures and fittings will also need to be reduced and just-in-time principles adopted for effective materials control.

Reading’s project, transferring advanced manufacturing technology to construction aims to apply ‘design to manufacture’, knowledge-based engineering technology to the construction industry’s ‘design to order’ culture.

The IDAC (Integrating Design and Construction) funding theme has also addressed some of these issues, but despite this, there are still further opportunities for focussed work in this area.

4.7 Whole life costing, sustainability, environmental impact and waste reduction

The implications for pre-assembly from whole-life costing have not really been explored to date. The proponents of pre-assembly argue that the increased quality possible in the factory environment should also reduce the whole life cost by reducing maintenance. However, historically, some pre-assembly applications have not taken life-cycle issues seriously and have actually built in problems for maintenance or replacement. There should be considerable opportunities to explore this issue in association with pre-assembly but to consider whole life costing properly would obviously require a long-term project and this would be against the current funding trend for projects of less than three years.

Sustainability seems to be used by some as a driver for increased pre-assembly, in particular less waste, noise, disruption etc resulting from factory-based activities. However, there has not been much research to date on this subject. The author understands that there are a number of projects in the current round of PII that seek to address such issues.

4.8 People issues, skills and training

Pre-assembly has a considerable impact on the people involved in its implementation. However, searching project data and reviewing deliverables confirms that people issues are not very well covered in the funded research into pre-assembly. This actually reflects the general lack of human factors research in the engineering sector.

However, the study of skills, education and training for prefabrication in housing by Westminster University covering Britain, Denmark, Germany and the Netherlands has just finished and the final report is imminent. The project team expects to be disseminating other publications in the near future. Several other projects include training packs in their deliverables.

Robert Gordon’s work on overcoming client and market resistance to prefabrication in housing should also cover some of these people issues as part of its investigation into socio-cultural resistance.

Health and safety is mentioned by a number of projects as one of the benefits of increased pre-assembly. The latest project from Loughborough will look at health and safety issues created by the use of pre-assembly and standardisation.

This area certainly provides an opportunity for more research, perhaps best focussed after the results of the Westminster work are made public.
4.9 New materials and technologies

In the main, the pre-assembly research and practice is not exploiting new materials or technologies. Much of the work has concentrated on increasing the applications of solutions that have been around for some time. For example the use of lightweight steel systems is now becoming a mature application. Also, in panelised pre-assembly, the innovation has mainly involved developing different formulations of panels. However, new applications for panel materials (e.g. Dupont’s Corian) are being used. Also, BSRIA’s work on innovative M&E installations includes the use of plastic (polybutylene) pipework, although in a sense this application is not really pre-assembly.

Another example of a new material that could impact on pre-assembly is the increased application of advanced composites to construction. So far, these have mainly been in footbridge construction, although cladding applications are also being explored.

Opportunities for new materials are being considered specifically in a current report being drafted for CRISP.

4.10 Information and communications technology (ICT)

Increased use of ICT is compatible with the move from a construction process to a manufacturing process. Projects that have specifically addressed ICT issues include:

- Warwick Market led homebuilding process engineering information system to suit mass customisation
- CIRIA Adding value by S&P improving predictability and efficiency by exploiting IT and automation
- Cranfield Decision making tools for controlled innovation evaluation of existing IT tools
- Celcon Factors affecting prefabricated masonry correct use of IT to control supply chain information flows
- Reading Transfer of advanced manufacturing technology using knowledge-based engineering to enable visualisation of design alternatives

In addition to these projects, many of the deliverables are utilising ICT through websites and CD outputs.

Because of the way that much of the pre-assembly supply chain is organised, the current applications for ICT are somewhat limited. This should be an area of further opportunity, but only if the supply chain moves to embrace ICT more fully.

4.11 Standardisation

Standardisation is often associated with pre-assembly and many of the projects have incorporated both aspects. The subject is covered in the companion CRISP review of standardisation research.

4.12 Measurement of success

Many of the publications to date provide some indication of specific benefits, but precise measurement has rarely been achieved. The difficulty of providing hard evidence for those who will consider pre-assembly in the future is one of the main barriers to its increased use.

Recently, some research has been concentrating on measurement issues, in particular CIRIA, BRE and BSRIA.

CIRIA’s tool kit provides a strategy for measurement and this is currently being tested on live construction projects. The strategy requires project teams to identify expected benefits early in the process and to decide how they will be measured and who will measure them – in other words to agree up-front what a success will look like. The approach attempts to cover the more tenuous benefits by using three benefit categories (first used by Construct IT for measuring benefits of IT Innovation):
• Efficiency Financially measurable
• Effectiveness Measurable, but not always in monetary terms
• Performance Having considerable influence on project outcomes but not easily measurable

However, CIRIA’s work is now moving away from this approach and adopting the key performance indicator (KPI) strategy which is being driven by the Construction Best Practice Programme (CBPP) and Movement for Innovation (MfI).

BRE’s CALIBRE can measure productivity and site based factors that can be very useful, however, benefits accrued elsewhere in the process will not be picked up in this way.

On a detailed level BSRIA have used site feedback forms to evaluate pre-assembly against traditional installation for building services on a project in Stansted Airport (Rowe-Roberts & Hawkins, 2000). This takes a step by step approach identifying positive lessons, room for improvement, relevant photo graphs, key learning points (process and product); and who needs to know about this.

Effective measurement of risk is still an emerging subject and does not appear to have been addressed in the pre-assembly research to date.

4.13 Sector specific motivators, facilitators, barriers and implications

Figure 5 shows the build-type bias for research work on pre-assembly. Residential construction is the largest sector at almost 40%. This evidence matches the indications from professional journals that have been concentrating on residential applications of pre-assembly over the last few years (see section 7.4). There appears to be a clear split in the residential sector with certain organisations using modular building for some of their schemes, others panel systems and still others concentrating only on traditional, on-site methods. Much of the TRADA and SCI work has concentrated on the residential sector.

More than a third of the funding is for projects where the build type is not specified. Some of these projects are dealing with issues that encompass all of the construction sectors and some, especially the more general 'innovation' projects are not sector specific.

Major building represents around 14% of overall pre-assembly research. Much of this work relates to building services, with some steel or concrete frames and some brickwork. Examples of applications from other sources indicate a substantial amount of non-volumetric pre-assembly such as panels, services and so forth, with some volumetric pre-assembly (toilet pods, plant rooms etc) and a certain amount of modular building (most low to medium rise).

Figure 5    Build-type bias in pre-assembly research (by value)
The civil engineering sector mainly concentrates on precast concrete and in particular bridges. These applications are not particularly innovative and the research work tends to concentrate on best practice rather than new innovation.

There is a small amount of work looking at maintenance, repair and refurbishment (MRR). One example of a project in this general area is the South Bank project on affordable housing adaptations using modular construction, funded under the DETR EQUAL (Extend Quality of Life) programme. However, this pilot study, completed in 2000 has not been able to secure follow-on funding to date. The Bartlett project, minimising the impact of refurbishment on customer movement only touches on pre-assembly as a small part of its work. Considering the market share of MRR, this would seem to be an area for further underpinning and application research.

Engineering construction (petro-chemical/power generation) uses pre-assembly on most of its projects, often to a very large extent. However, they do not appear to be doing much research in the area, at least not government funded. There is anecdotal evidence to suggest that pre-assembly is a mature subject in the engineering construction sector and as such does not require the same level of fundamental research. Rather, the opportunities are well understood and specific applications are developed by individual organisations for each project. There do not seem to be any real barriers to the implementation of pre-assembly in engineering construction, which may also account for the fact that it does not seem to be a contentious subject worthy of further research investigation in that sector.

There may be opportunities for some of the work that has concentrated on particular sectors (e.g. TRADA or SCI) and seeking to apply it elsewhere. This approach has been employed to some extent by the Nottingham MEDIC team who are extrapolating M&E best practice into other areas such as building structure.

5 BEST PRACTICE EXAMPLES

5.1 CBPP (Construction Best Practice Programme)

The Construction Best Practice Programme (CBPP) identifies, publicises and supports the use of improved business and management practices for the construction industry. It is funded by the Department of Environment, Transport and the Regions and is steered by the Government and the Construction Industry Board. CBPP links closely with M4I.

CBPP disseminates best practice guides for standardisation and pre-assembly both in hard copy and through its website.

5.2 M4I (Movement for Innovation)

The Movement for Innovation was launched in 1998 to implement the challenges of the Egan report to achieve annual improvements of:

- 10% reduction in capital cost and construction time
- 20% reduction in defects and accidents
- 10% increase in productivity and profitability
- 20% increase in predictability of project performance

M4I works with subject specific groups and regional clusters. The clusters provide a forum where industry-driven research can be discussed and results disseminated. The main thrust of the movement is demonstration projects which are published on the M4I website. These report ‘innovative’ projects, describing the project and explaining the nature of the innovation. Some are able to provide hard evidence of benefit but others, to date at least, are mainly anecdotal.

Searching for pre-assembly, prefabrication, modular, manufacture and factory identifies 23 projects. These projects provide a wide variety of building types and potential applications. However, many of them, to date, have not been developed on the M4I website and so the exact nature of the innovation and how it relates to pre-assembly cannot be gauged fully. The projects are listed on the next page, identifying the nature of the pre-assembly innovation where possible. Similar lists of exemplar projects are available from groups such as the Housing Forum, but these were not reviewed in this commission.
<table>
<thead>
<tr>
<th>No</th>
<th>Project</th>
<th>Nature of pre-assembly innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Dawlish and Sidmouth project</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>10</td>
<td>288 Bishopsgate office building</td>
<td>Pannellised cladding; pre-assembled plantroom, sprinkler pipework, AC fan coil units with valves and controls</td>
</tr>
<tr>
<td>19</td>
<td>Synthetic Chemistry building</td>
<td>TBA</td>
</tr>
<tr>
<td>27</td>
<td>Gatwick South Terminal International Dept Lounge Extsn</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>28</td>
<td>M60 Manchester Outer Ring Road, Denton-Middleton Scn:Con3</td>
<td>Not obvious from project data – maybe road bridges</td>
</tr>
<tr>
<td>43</td>
<td>Slough: 158 Edinburgh Avenue: Meggitt</td>
<td>Pre-assembled cladding panels</td>
</tr>
<tr>
<td>54</td>
<td>Tamar Bridge – strengthening and widening</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>65</td>
<td>Maine Vapour Recover project</td>
<td>Design, fabrication and installation of a 1200t process module</td>
</tr>
<tr>
<td>74</td>
<td>Oxford Industrial Park development</td>
<td>Not obvious from project data – maybe steel frame and/or cladding</td>
</tr>
<tr>
<td>109</td>
<td>St John the Evangelist Church</td>
<td>Not obvious from project data – maybe light steel framing</td>
</tr>
<tr>
<td>119</td>
<td>Luton Brache Beafeater &amp; Travel Inn</td>
<td>Timber frame</td>
</tr>
<tr>
<td>128</td>
<td>Livingston Drive Thru</td>
<td>Modular building – relocation</td>
</tr>
<tr>
<td>132</td>
<td>Manhole reinstatement A5036, Sefton</td>
<td>Pre-assembled manholes – Ready-Raise Units</td>
</tr>
<tr>
<td>138</td>
<td>Classroom block, Royce School, Hulme</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>143</td>
<td>Christ Church Court</td>
<td>Not obvious from project data – maybe pre-formed reinforcement for insitu concrete frame</td>
</tr>
<tr>
<td>146</td>
<td>Mondial House</td>
<td>Not obvious from project data – maybe pre-assembled M&amp;E works</td>
</tr>
<tr>
<td>157</td>
<td>100 Leman Street</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>158</td>
<td>Veterinary Laboratories Agency</td>
<td>Not obvious from project data – maybe composite cladding panels</td>
</tr>
<tr>
<td>162</td>
<td>Gateshead Millennium bridge</td>
<td>TBA</td>
</tr>
<tr>
<td>164</td>
<td>Windsor Hall, University of Reading</td>
<td>Not obvious from project data</td>
</tr>
<tr>
<td>168</td>
<td>Harry Ramsden restaurant</td>
<td>Light steel framing</td>
</tr>
<tr>
<td>177</td>
<td>Slough: 208 Bath Road: W6191</td>
<td>Clip-on rainscreen spandrel panels – multi-service pre-assembled building services – Bamtec pre-assembled reinforcement and shear studrails</td>
</tr>
<tr>
<td>187</td>
<td>Wythenshaw Hospital PFI project: Acute Building</td>
<td>Not obvious from project data – maybe light steel framing</td>
</tr>
</tbody>
</table>

5.3 Other Publications

A number of other publications include examples of best practice. Of particular note are the following:
- Standardisation and pre-assembly – adding value to construction projects
- 14 detailed case studies and numerous abridged examples.
- Offsite fabrication – prefabrication, pre-assembly and modularisation
- 18 detailed case studies and numerous abridged examples.
Prefabrication and pre-assembly – applying the techniques to building engineering services
Smith, M (ed), 1999, Building Services Research & Information Association (BSRIA), Old
Bracknell Lane West, Bracknell, Berkshire RG12 7AH, UK
9 detailed case studies and numerous abridged building services examples

Appendix 6 provides a summary bibliography for pre-assembly.

5.4 Professional Journals and Magazines

Professional journals and magazines have been reviewed for the period 1998-2000 to identify
examples of pre-assembly and these are presented in Appendix 7. The main journals that were
reviewed included:
- Building
- Building Homes
- Construction News
- Building Design
- NCE (New Civil Engineer)
- ENR (Engineering News Record – USA)

The articles fall into two main categories. Some are very terse and merely state the news item –
either an application of pre-assembly or a change in business circumstances. Others are longer,
feature articles which provide more information of the applications described. However, these articles
often appear to overstate the case, either claiming world domination (e.g. Absolutely Prefabulous) or
complete collapse for pre-assembly (e.g. Is prefab just a fad?). They also tend to concentrate on
headlines and careful reading of the text is required to un-pick the actual content. However, even
though the quality of the reports varies widely, they do provide an indication of the type and nature of
practice in the area.

6 WORK OUTSIDE THE UK

6.1 Summary review of international research and publications

Few reviewed projects addressed international aspects. Westminster’s transnational study skills for
housing prefabrication looked at Britain, Denmark, Germany and the Netherlands. However, the
author has so far been unable to obtain copies of the outputs from this work and so further comments
can not be made.

FutureConstruct is an initiative to increase research and technological development within the
European construction industries. Their report espouses lean construction, higher industrialisation,
and off-site fabrication.

The CIRIA ‘adding value to construction projects’ work included an international review that was
written by David Gann of SPRU. He found that in general the factors affecting standardisation and
pre-assembly are the same, irrespective of geographic location. However, he stressed that the
following should be considered:
- Local technological expertise
- Availability of trained operatives
- Approach regarding maximising or minimising labour (Africa versus Japan)
- Acceptability of standard solutions (more acceptable outside Europe and the USA)

Many international publications are dominated by Engineering Construction – seemingly pre-
assembly and standardisation are the only viable alternatives for most of these large power
generation or petro-chemical projects.

International civil engineering examples appear to concentrate on bridges, largely precast concrete
and largely non-innovative – in that they are really adapting precast existing technology.

There does seem to be an increased interest in pre-assembled (and standardised) domestic buildings
throughout Europe. Interestingly, pre-assembly of the building structure and fabric seem to be
stressed in articles covering innovative technologies such as PV cells for power generation.
There has been a series of articles in Building Homes describing non-UK approaches to domestic construction many of which include manufacturing innovations.

Several recent papers originating from mainland Europe cover maintenance and repair issues relating to their large stock of existing (and now dilapidated) precast concrete high-rise buildings.

Asko Sarja (1998) provides a useful commentary on various overseas applications of open industrialisation, which incorporates pre-assembly. Whilst not being completely comprehensive, he comments on applications in the following areas:

- European Union, Central and Western Europe
  - Denmark; Finland; France; Germany; The Netherlands; Spain; Sweden; United Kingdom; Norway; Switzerland; Czech and Slovakian Republics; Croatia; Slovenia; Yugoslavia; Hungary; Poland; Romania.
- Russia and GIS countries
- Northern Asia
  - Japan; Korea; China
- South and Southeast Asia
  - Afghanistan; Bangladesh; Sri Lanka; Thailand; Indonesia; Malaysia; Pakistan; Philippines; Nepal; India; Taiwan.
- Northern America
  - Canada; USA
- South and Central America
  - Argentina
- Africa
  - Nigeria
- Middle East
  - Kuwait; Libya; Saudi Arabia; Israel

An example of some of Sarja’s comparisons are shown below (adapted from Sarja 1998):

<table>
<thead>
<tr>
<th>Country</th>
<th>General</th>
<th>Materials</th>
</tr>
</thead>
</table>
| Finland | Dropped volume | One family houses: wood
New buildings mainly in the largest towns | Detached houses: wood/concrete
Small sites pre-fabrication dominant | Multi-storey apartments: concrete
Construction 8% GNP | Offices: concrete, some steel
| India | Vast shortage of houses | Rural: local natural materials
73% population in countryside | (bamboo, earth, timber, stone, bricks)
Wide variety of technology and materials | Urban: bricks, concrete, stone
| Israel | Rapid population, building & economy growth | Concrete dominant
Multi-family houses dominant | Small share of lightweight steel or timber
Construction 12% GNP | | |
| Japan | Traditional timber buildings | One family houses: timber/concrete
Large production | Multi-storey apartments: concrete
Great variety in building size | Offices: Steel
| Sweden | Dropped volume | Single and detached houses: wood
Smaller projects | Apartments: concrete
Construction 12% GNP | Offices: concrete, some steel
| USA | 10.5% Multifamily | Single houses: wood
3.5% HUD code | Multi-family: concrete/steel
86% single family | Offices: steel/concrete

Notwithstanding the number of international examples cited, care must be taken in interpreting and applying non-UK examples.
6.2 Conseil Internationale de Batiment (CIB)

The CIB is an international research club, based in the Netherlands and acting as a world-wide network for researchers working in the construction management area. The CIB operates through a number of working commissions that are groupings of experts in particular fields who meet regularly, convene conferences and produce state of the art reports. The CIB has two working commissions that cover the area of pre-assembly:

- open industrialisation in building
- open architecture

Open industrialisation in building has been active for many years. Its main recent publication has been the Sarja book of the same name cited earlier in this report. Historically, the commission has been dominated by northern European precast concrete open systems building. Latterly this commission has become less active and may well be wound up.

The open architecture commission is still very active and is mainly driven by architects, concentrating mainly on residential buildings. Their focus is largely standardisation and flexibility rather than pre-assembly.

The CIB has also obtained an EU grant for work on a network for performance-based building that may have implications for pre-assembly. Manufacture and assembly, as replacements for construction, remain a focus for CIB, forming part of the challenge set for the research community at the CIB triennial world congress in New Zealand in April 2001.

6.3 Japanese building

Japanese house building is worthy of particular mention because it has been probably the most quoted non-UK example of manufacturing techniques for construction. Much of the interest was generated following a DTI funded OSTEMS visit by Laing (David Bottom), Arup (Steve Groak), SPRU (David Gann) and Davis Langdon & Everest (Jim Miekle). This resulted in a report published by CIRIA in 1994 entitled ‘Innovation in Japanese prefabricated house building industries.’ Although this visit was some time ago, the issues are still relevant. Gann (in CIRIA 1999) argues that the 1990’s Japanese model was successful because:

- the volume of demand existed
- it delivered a high degree of choice and flexibility
- customers were demanding and prepared to pay for quality
- it produced quality products
- minimum on-site time was important

This was compared to the failure of the UK’s 1960s experiment with system building which was unsuccessful because:

- the volume of demand was not forthcoming
- it was public sector (political) and not market (demand) led
- a key objective was economies of scale

Gann argues that current successful examples of standardisation and pre-assembly are closer to the Japanese 1990s model than the UK 1960s because:

- they are demand driven
- reduced cost is not the main objective
- technical solutions are available that can provide quality and do not restrict choice
- clients in the construction industry are willing to engage in constructive dialogue

Japanese building has also been the stimulus for a European research project, FutureHome. The Japanese part of the project has focussed on high-rise apartments, claiming to achieve a 70% reduction in labour costs, 20% reduction in material costs and an overall saving of 50% (Takada, 2000). The FutureHome project is developing design and assembly methods, fundamental technologies for field factories and autonomous agents for production information management, decision-making support systems, simulation systems, and production information collection systems. The main UK/EU application is in the residential sector.
7 CONCLUSIONS

7.1 Research Review

Almost £5 million has been invested by DETR and EPSRC in research projects that include pre-
assembly in construction since 1997. Of this total figure, around £1.1 million covers general
innovation which includes pre-assembly, with the remainder concentrating more specifically on pre-
assembly. Because of the gearing of the funding, the actual overall value of the research is twice the
funded value (i.e. ~£10 million), with the extra being funded, usually in kind, by the industry partners.

Pre-assembly has been well represented in the funding schemes over recent years although it is
often disguised as part of broader research projects on innovation and frequently different terms are
used instead of pre-assembly. Many projects also combine pre-assembly with standardisation (for
more information on this see CRISP report 00/20). Many of the projects reviewed are still in progress
and so the outcomes are not yet fully understood. This work has focussed on various different
technologies and materials, often led by industry bodies with obvious priorities set by their
membership. There may be an opportunity to check for cross fertilisation between these groups and
between the findings of their respective projects.

In addition to their input to government funded projects, industry is doing its own work, but the results
are often commercially sensitive and confidential. In particular there has been a recent increase in
developments in the residential sector.

Many different research teams are also involved, with a small number doing most of the work,
however, there is little evidence of coordination between teams. This has resulted in a challenge for
future work to ensure that it is organised in a holistic manner and takes best advantage of the other
work that is already underway.

Furthermore, the deliverables from the funded projects vary considerably, from CDs, videos, high-
impact publicity documents to word-processed reports and learned journal papers. Some
deliverables have been disseminated widely and others hardly at all. Websites have been used, but
their quality and accessibility again vary widely. Few of the projects have developed the deliverables
to the level of practical ‘sharp-end’ guidance and advice.

The existing DETR and EPSRC websites have not been kept up to date and information on
deliverables have often not been added to the data. There appears to be no one place where
interested parties can go to obtain information about pre-assembly research.

There is a good opportunity to draw together these deliverables and make them more accessible
providing the lead-researchers of the projects are co-operative. Also, future projects could be
encouraged to concentrate more strongly on effective dissemination. There are also challenges to
take some of the existing work and apply it in a broader sphere, or in a more co-ordinated, strategic
manner. The various research networks may be a good way of achieving this, but they have not
been going for long enough to evaluate their effectiveness.

7.2 Issues raised by the research

Benefits from pre-assembly are often realised elsewhere in the construction process. Some leading
repeat-order clients have started to acknowledge this and moved towards better consideration of pre-
assembly, but the one-off clients are harder to involve in this movement. Advisors to the ‘one-off’
client sector appear to be significant barriers to further implementation.

The principle of the important influence of procurement routes and supply-chain relationships for pre-
assembly implementation appears to be accepted. But there are many other drivers for procurement
routes and there has been much work already completed in this area. By contrast, there has been
little work on the link between pre-assembly and formal or contractual requirements, nor on the effect
of legislation.

Successful implementation of pre-assembly depends on a shift in the industry from a construction-
dominated process towards a manufacturing oriented approach. This has implications for the
integration of the supply chain, appointment of suppliers, information flow and decision timing but,
whilst it has been acknowledged, it does not seem to have been worked out in the projects completed
to date.

Whole-life costing studies have not been completed for pre-assembly and, although they have been
raised, issues of sustainability in pre-assembly have not really been resolved.

People issues have not been covered in much of the existing work except for a project on health and
safety and one on skills, education & training. Further opportunities in these areas could be
established once these projects have delivered.

There is little evidence of the study of new materials for pre-assembly, although this subject is
covered in more detail in another CRISP report recently commissioned.

Because of the way that much of the pre-assembly supply chain is organised, the current applications
for ICT are somewhat limited. This should be an area of further opportunity, but only if the supply
chain moves to embrace ICT more fully.

Existing methods of measuring project success are not developed sufficiently to adequately evaluate
the benefits of pre-assembly, but a number of existing projects are currently working in this area.
Effective measurement of risk is still an emerging subject and does not appear to have been
addressed in the pre-assembly research to date.

The research on pre-assembly is more or less evenly split between general (no specific sector)
(36%), the residential sector (39%), and the remainder major building and civil engineering with a
small amount covering maintenance, repair and refurbishment (MRR). In particular, the MRR sector
is likely to be an area of opportunity. There appears to be little work aiming to coordinate pre-
assembly work or apply lessons learnt in one sector to the challenges of another sector.

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17), Taiwan, September 2000, pp 983-989.

END NOTES

i  Taken from the EPSRC website - www.epsrc.ac.uk/epsrcweb/index.asp
ii  Taken from the DETR PII website - www.construction.detr.gov.uk/cirm/cirmhome.htm
iii  Taken from the EPSRC website - www.epsrc.ac.uk/epsrcweb/index.asp
iv  Taken from the BSRIA website – www.bsria.co.uk
v  Taken from the TRADA website - www.trada.co.uk
vi  Taken from the SCI website - www.steel-sci.org
vii  Taken from the RCC website - www.rcc-info.org.uk
viii Taken from the CIRIA website – www.ciria.org.uk
Appendix 1

List of CRISP reports on the broader subject of innovation
Appendix 1  List of CRISP reports on the broader subject of innovation

98/4 Linking construction research and innovation to research and innovation in other sectors
Roger Flannagan, University of Reading
June 1999
14 pages
Technology and Performance theme group
Report available from CRISP

99/12 How can regulations promote construction innovation
David Gann, SPRU
October 1999
Executive
Report available from CRISP

99/17 Technological change: the next leap towards lean construction
Mike Townsend, Mace
January 2000
Technology & Components Task Group
Report available from CRISP

99/17 The contribution that technological change could make to meeting the objectives of Rethinking Construction
Neil Noble, Ove Arup & Partners
January 2000
Executive and Technology & Components Task Group
Report available from CRISP

00/06 Review of proceedings: Workshop - The contribution that technological change could make to meeting the objectives of Rethinking Construction
Richard Lorch Associates
July 2000
Executive and Technology & Components Task Group
Report available from CRISP
Pre-assembly in construction

Appendix 2

Funded research review for pre-assembly
<table>
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<th>Ref</th>
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<td>38/7/204</td>
<td>Clients' toolbox for demonstrating optimised use of standardisation &amp; pre-assembly</td>
<td>CIRIA - Lboro Ann Alderson Alistair Gibb</td>
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<td>M38910/01</td>
<td>COMPREST: cost model for pre-assembly and standardisation in construction</td>
<td>Lboro Chris Pasquie Alistair Gibb</td>
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<td>Decision-making tools for controlled innovation in construction</td>
<td>Cranfield John Rogerson</td>
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<td>Design guide &amp; innovation of modular units</td>
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<td>39/3/491</td>
<td>Development of monocoque panel systems for long span structures</td>
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<td>Factors affecting the use of pre-fabricated masonry systems</td>
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<td>Lboro Alistair Gibb</td>
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<td>IMMPPREST: interactive model for measuring pre-assembly &amp; standardisation benefit across the supply chain</td>
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<td>Innovation &amp; best practice in flexible &amp; modular building solutions</td>
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<td>Innovation &amp; strategy: the link for building services</td>
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<td>Overcoming client &amp; market resistance to pre-fabrication &amp; standardisation in housing</td>
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<td>38/8/115</td>
<td>Re-engineering timberframe affordable house construction: demonstration project</td>
<td>TRADA Geoff Pitts</td>
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<td>39/12/8</td>
<td>Standardisation &amp; skills: a transnational study of skills, education &amp; training for prefabrication in housing</td>
<td>Westminster Clarke/Gould</td>
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<td>LINK 86 X</td>
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<td>Technical specification for pre-engineered modular steel construction for residential and similar buildings</td>
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<td>Timber sector best practice initiative</td>
<td>BRE Peter Bonfield</td>
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<td>39/3/239</td>
<td>Transfer of advanced manufacturing technology to construction</td>
<td>Reading Richard Barlow</td>
<td>1998</td>
<td>PII 180 X</td>
<td>X</td>
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<td>38/6/161</td>
<td>Uptake of productivity improvements</td>
<td>BSRIA Rowe-Roberts/ Hawkins</td>
<td>2000</td>
<td>?? X</td>
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Pre-assembly in construction

Appendix 3

EPSRC-funded projects on pre-assembly
### Appendix 3  EPSRC-funded projects on pre-assembly

#### Abstract, Outputs & Deliverables, Investigator details

<table>
<thead>
<tr>
<th>EPSRC Grant Ref</th>
<th>Project Title</th>
<th>Abstract</th>
<th>Outputs and Deliverables</th>
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<td>GR/K66963/01</td>
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<td>see GR/M21942/01</td>
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<td>GR/L99555/01</td>
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#### Investigator Details:

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Department</th>
<th>Telephone</th>
<th>Fax</th>
<th>EMail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr Rajat Roy</td>
<td>Warwick University</td>
<td>Sch of Engineering</td>
<td>024 76523968</td>
<td>01203 524307</td>
<td><a href="mailto:roy.r@eeyore.wmg.warwick.ac.uk">roy.r@eeyore.wmg.warwick.ac.uk</a></td>
</tr>
<tr>
<td>Jones, S. P.</td>
<td>Cardiff University</td>
<td>Welsh School of Architecture</td>
<td>029 2087 4078</td>
<td>029 2087 1625</td>
<td><a href="mailto:jonesp@cf.ac.uk">jonesp@cf.ac.uk</a></td>
</tr>
<tr>
<td>Mr W Forster</td>
<td>Cardiff University</td>
<td>Welsh School of Architecture</td>
<td>029 20874000</td>
<td></td>
<td><a href="mailto:forsterw@cardiff.ac.uk">forsterw@cardiff.ac.uk</a></td>
</tr>
<tr>
<td>Dr MM Naim</td>
<td>Cardiff University</td>
<td>Maritime Studies &amp; International Trans</td>
<td>029 20874271</td>
<td>029 20874301</td>
<td><a href="mailto:naimmm@cf.ac.uk">naimmm@cf.ac.uk</a></td>
</tr>
</tbody>
</table>
**GR/M10915/01**  
**Standardisation of brick work construction**  
**Abstract:**  
The project aim is to retain the flexibility and the aesthetic durability advantages of traditional brickwork, whilst increasing speed, reliability and efficiency of the construction process, resulting in the enhanced cost effective quality of the finished work. A single solution to standardisation is unlikely to be suitable for the whole range of brickwork schemes and two basic approaches to the incorporation of standardisation are being investigated. The objectives will develop proposals for: -  
- On-site construction- Standardised details and construction procedures.  
- Prefabrication- Design, manufacturing, transportation, jointing and erection procedures.  
Underlying both of the areas will be a study of improved approaches to the materials specification, handling and storage, quality assurance and supply chain management.  
**Outputs and Deliverables:**  
Website [http://sst.tees.ac.uk/mcns-brickwork/](http://sst.tees.ac.uk/mcns-brickwork/)  

<table>
<thead>
<tr>
<th>Investigator Details:</th>
<th>Investigator Details:</th>
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<tbody>
<tr>
<td>Name: Professor B Hobbs</td>
<td>Name: Professor Nashwan Dawood</td>
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<tr>
<td>Institution: Teesside University</td>
<td>Institution: Teesside University</td>
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<tr>
<td>Department: School of Science &amp; Technology</td>
<td>Department: School of Science &amp; Technology</td>
</tr>
<tr>
<td>Telephone: 01642 384408 Fax: 01642 384411</td>
<td>Telephone: 01642 342410 Fax: 01642 342401</td>
</tr>
<tr>
<td>EMail: <a href="mailto:B.Hobbs@Tees.ac.uk">B.Hobbs@Tees.ac.uk</a></td>
<td>EMail: <a href="mailto:n.n.dawood@tees.ac.uk">n.n.dawood@tees.ac.uk</a></td>
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</table>

**GR/M21942/01**  
**Market-led homebuilding as a manufacturing process- phase II**  
**Abstract:**  
The housebuilding industry has been slow to adopt new working practices essential for product quality and customer focused operations. The proposal is aimed at four areas to support a move towards a mass customisation industry and improvements in product quality. Rapid product configuration to customer specification and consistency of the build process will require an increasing use of pre-fabricated parts, and the first project will study the connectivity of various build technologies and customisation options they provide. The supply lead times for fixtures and fittings will also need to be reduced and just-in-time principles adopted for effective materials control; the second project will formulate policies for a supplier development programme, and study the implementation process. Mass customisation requires a customer to play a direct role in product design, and the third project will research and develop a product configuration and visualisation customer interface for the new order fulfilment process. A clear definition of the build process, effective communication of best practice and feedback are important to develop a culture for quality; the fourth project will research and develop a process engineering information system to help create such a culture, and deal effectively with product variants to support mass customisation.  
**Outputs and Deliverables:**  
Spin-off company wholly owned by lead partner Westbury  
Various papers including CME journal 1999, Development of a customer focused strategy in speculative housebuilding and ARCOM conference 1999, Liverpool  

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<tr>
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<td>EMail: <a href="mailto:roy.r@eeyore.wmg.warwick.ac.uk">roy.r@eeyore.wmg.warwick.ac.uk</a></td>
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</tbody>
</table>
### GR/M39190/01
**COMPREST: cost model for pre-assembly and standardisation in construction (Pilot study)**

**Abstract:**
Short pilot study project to test the concept of a cost model for standardisation and pre-assembly – concentrating on mechanical services for major buildings. COMPREST led to the IMMPREST project GR/N34000/01.

The pilot study investigated the data currently available for measuring the cost implications of standardisation and pre-assembly, and identified that some data related to easily identifiable costs such as resources and site costs; and that these costs can be measured using traditional QS/estimating techniques. However, it was clear from the pilot study that these costs were only part of any benefit evaluation exercise. Several others costs were incurred, but were either included in existing accounting systems, were unidentifiable individually, or were not accounted for at all.

**Outputs and Deliverables:**
- Website – [http://www.lboro.ac.uk/research/immprest/proj.htm](http://www.lboro.ac.uk/research/immprest/proj.htm)

**Investigator Details:**
- **Name:** Dr CL Pasquire
- **Institution:** Loughborough University
- **Department:** Civil & Building Engineering
- **Telephone:** 01509 222895
- **Fax:** 01509 223981
- **EMail:** c.l.pasquire@lboro.ac.uk

### GR/M42107/01
**Innovation in small construction firms**

**Abstract:**
The project will bring together eight SMEs to work collectively towards the above objectives. They will be introduced to: two large construction firms who are exponents of successful innovation; leading international practice from Scandinavia; and they will work with an experienced group of academics with specialist knowledge of innovation. Within this very stimulating environment the main thrust of the project will be to: Assess the current state of innovation management within the construction SMEs through an audit of the business and organisational drivers of innovation. This will be linked to examples of innovation within the firms. Based on the above understanding, work with the SMEs closely in an action research mode to develop best practice in creating and supporting innovation. The project will deliver a good practice guide giving senior managers in construction SMEs a clear vision of the importance of innovation and effective innovation management, so that they can effectively lead the development of an ongoing capacity to innovate successfully. The guide will also provide practical examples so that, at an operational level, effective innovations can be designed.

**Outputs and Deliverables:**
- Project still underway – several conference papers (CIB W65, Reading 2000; AEC 2001; ARCOM 2001)

**Investigator Details:**
- **Name:** Professor PS Barrett
- **Institution:** Salford University
- **Department:** Construction & Property Man (Res Cen)
- **Telephone:** 0161 2955588
- **Fax:** 0161 2953862
- **EMail:** p.s.barrett@surveying.salford.ac.uk
| **GR/M42114/01** | **Investigator Details:**  
*Innovation in small construction firms*  
*Abstract:*  
The project will bring together eight SMEs to work collectively towards the above objectives. They will be introduced to: two large construction firms who are exponents of successful innovation; leading international practice from Scandinavia; and they will work with an experienced group of academics with specialist knowledge of innovation. Within this very stimulating environment the main thrust of the project will be to: Assess the current state of innovation management within the construction SMEs through an audit of the business and organisational drivers of innovation. This will be linked to examples of innovation within the firms. Based on the above understanding, work with the SMEs closely in an action research mode to develop best practice in creating and supporting innovation. The project will deliver a good practice guide giving senior managers in construction SMEs a clear vision of the importance of innovation and effective innovation management, so that they can effectively lead the development of an ongoing capacity to innovate successfully. The guide will also provide practical examples so that, at an operational level, effective innovations can be designed.  
**Outputs and Deliverables:**  

| **GR/M44415/01** | **Investigator Details:**  
*Network on lean construction*  
*Abstract:*  
Set up a UK based network to develop and progress the theme of 'lean construction' by joint university/industry research projects as one route to improving the efficiency of the construction processes and provide added value to clients. This is in accordance with industry aims and IMI "Construction as a Manufacturing Process" Programme. The initial network links one university (Cranfield) with specific expertise in manufacturing and some knowledge of construction management with leading universities concerned with construction management issues (Salford, Reading, Loughborough, Dundee) and a university (bath) with expertise in both manufacturing and construction, as well as architects, contractors, consulting engineers and the national research institution (BRE). A major activity will be a series of specialist interactive workshops leading to the development and publication of a series of interpretative reports. These reports will be available for wider dissemination but their main purpose will be to define areas where there are knowledge gaps in the application of 'lean' concepts to construction so that network members can develop collaborative research programmes and provide input to policy development in this area.  
**Outputs and Deliverables:**  
Website   http://www.cranfield.ac.uk/sims/quality/lean_con.html  
Current, on-going network  
4 position papers published:  

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*Pre-assembly in construction – CRISP 00/19 – Gibb, A.G.F.*
Standardisation & skills: a transnational study skills education & training for prefabrication in housing

Abstract:
The objective of the research is to assess how far the extension of manufacturing-based methods in the British construction industry is deterred by existing skill and education/training structures and to suggest areas for improvement. It will: identify different forms of prefabrication and standardisation associated with different skill constellations in Britain, Denmark, Germany and The Netherlands; describe the skills (including the design of multi-skilling), qualifications and training of all the different participants in more traditional housing construction compared with those for non-traditional forms of construction; outline the related business processes (including client/contractor/subcontractor relations) and supply chains (from design to manufacturing to assembly) and firm/project organisation. The focus is on a selection of housing association projects and a survey will be conducted of the housing associations, designers, contractors, subcontractors and operatives concerned. The project is for two years and its output is a research report/book, articles, handbooks and a summary booklet for wide dissemination through a conference, seminars and publications.

Outputs and Deliverables:
Unknown

Knowledge/experience transfer from prefabrication of building services to construction designers & clients

Abstract:
Off-site manufacturing (or prefabrication) for building and infrastructure type construction is claimed to benefit customers by increasing the quality of the work, reducing the uncertainty and reducing the overall cost of projects. It is also claimed to reduce and simplify maintenance and to extend life-cycles whilst reducing life-cycle costs. The overall objectives of this work are to increase the use of off-site prefabrication in these sectors of the construction industry by collecting the knowledge of leading exponents of prefabrication and providing it, in a useable form, to the rest of the industry. This will help designers to produce designs which take advantage of prefabrication techniques and demonstrate their benefits in quantitative as well as qualitative terms. This will enable the decision to whether or not to prefabricate to be made scientifically. The project will initially concentrate on the provision of services and structure to buildings by means of large prefabricated units. The knowledge which will be collected and used will include: design methods for prefabrication; on-site erection time, resources and methods for prefabrication; on-site time and resources for traditional build equivalents; and quality measures. The project will produce the knowledge in a useable form and employ CDs for dissemination.

Outputs and Deliverables:
Medic website  www.civeng.nottingham.ac.uk/medic/start.htm
GR/M86392/01
Overcoming client & market resistance to pre-fabrication & standardisation in housing

**Abstract:**
This proposal builds on an earlier submission to MCNS (Meeting Client Needs through Standardisation) which proposed an examination of the cultural and other barriers to prefabrication in the house-building industry. Its central premise is that, in order to optimise the efficiency and worth of new housing activity, client resistance to the introduction of greater levels of pre-fabrication and standardisation needs to be understood and overcome. The project adopts a broad definition of the 'client', though the primary focus is on the purchaser and end user of housing. The aims of the research will be achieved in a two stage process, funding for the first stage of which is now sought. The first stage involves the development and testing of new, predominantly financial models through which the resistance to pre-fabrication in housing can be eased. The second stage involves the practical, on-site demonstration of both product and process developments which can increase market penetration of, and confidence in, pre-fabrication and standardisation. The first stage is the primary component which requires research funding. The second stage is a near-market, developmental phase which, it is hoped, will be carried out with industrial sponsorship.

**Outputs and Deliverables:**
Unknown

**Investigator Details:**
Name: Dr HM Edge
Institution: The Robert Gordon University
Department: Construction, Property & Surveying
Telephone: 01224 263539   Fax: EMail: m.edge@rgu.ac.uk

**Investigator Details:**
Name: Mr RW Pollock
Institution: The Robert Gordon University
Department: Construction, Property & Surveying
Telephone: 01224 263700   Fax: 01224 263777
EMail:

**Investigator Details:**
Name: Dr A Al-Hajj
Institution: The Robert Gordon University
Department: Construction, Property & Surveying
Telephone:   Fax: EMail:

**Investigator Details:**
Name: Mr GA Slaven
Institution: The Robert Gordon University
Department: Faculty of Design
Telephone: 01224 263539   Fax: 01224 263737
EMail: g.a.slaven@rgu.ac.uk
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| GR/N02917/01 | Minimising the impact of refurbishment on customer movement - RaCMIT | No abstract available                                                                       | Project recently commenced – Conference paper (Cannes 3/01)  First working paper on customer movement in preparation. | Name: Dr GM Winch  
Institution: University College London  
Department: Bartlett Sch of Architecture & Planning  
Telephone: 020 76 79 59 21  
Fax: 020 79 16 18 87  
EMail: g.winch@ucl.ac.uk |
| GR/N34000/01 | IMMPREST: interactive model for measuring pre-assembly & standardisation benefit across the supply chain   | The primary aim is to produce an interactive modelling system (IMMPREST) that facilitates the evaluation of benefits arising from the use of pre-assembly and standardisation. The system will support design and procurement decisions for clients, designers, cost advisors, and the delivery supply chain. Additional support for the delivery supply chain will benefit marketing and measurement of business performance.  This builds on the pilot study project COMPREST - GR/M39190/01 | Website - http://www.lboro.ac.uk/research/immprest/index.htm | Name: Dr CL Pasquire  
Institution: Loughborough University  
Department: Civil & Building Engineering  
Telephone: 01509 222895  
Fax: 01509 223981  
EMail: C.L.PASQUIRE@LBORO.AC.UK |
| GR/R18734/01 | INCONIN: International Collaboration In Construction Innovation  | A network project within CIB  
Outputs and Deliverables:  
Project recently commenced – No public outputs to date | Name: Alistair Gibb  
Institution: Loughborough University  
Department: Civil & Building Engineering  
Telephone: 01509 223097  
Fax: 01509 223981  
EMail: a.g.gibb@lboro.ac.uk  
Web: http://www-staff.lboro.ac.uk/~cvagg/ | Name: Dr GM Winch  
Institution: University College London  
Department: Bartlett Sch of Architecture & Planning  
Telephone: 020 7679 5921  
Fax: 020 7916 1887  
EMail: g.winch@ucl.ac.uk |
| GR/R19984/01 | Investigator Details:  
Network for the integration of design and construction to foster innovation in the construction industry supply chain  
Abstract:  
An enterprise activity with the ultimate aim of identifying research needs in integrated design and production, working very closely with M41.  
Outputs and Deliverables:  
Project recently commenced – No public outputs to date |
| --- | --- |
| Investigator Details:  
Name: Professor JA Powell  
Institution: Salford University  
Department: Research & Graduate College  
Telephone: 0161 7455464  
Fax: 0161 7455553  
EMail: j.a.powell@salford.ac.uk |
| Investigator Details:  
Name: Professor D Lenard  
Institution: Salford University  
Telephone: 01612955076  
Fax: 0161 295 5011  
EMail: d.lenard@salford.ac.uk |
| GR/R20038/01 | Investigator Details:  
HASPREST Health and safety implications of pre-assembly & standardisation  
Abstract:  
The primary aim is to provide guidance on health and safety issues for those using standardisation and pre-assembly in construction.  
Outputs and Deliverables:  
Project due to start August 2001 |
| Investigator Details:  
Name: Alistair Gibb  
Institution: Loughborough University  
Department: Civil & Building Engineering  
Telephone: 01509 223097  
Fax: 01509 223981  
EMail: a.g.gibb@lboro.ac.uk  
Web: http://www-staff.lboro.ac.uk/~cvagg/ |
Pre-assembly in construction

Appendix 4

DETR Funded Projects on Pre-assembly
DET-funded projects on Pre-assembly
Background, Objectives and Relevant Publications & Outputs

Projects on Pre-assembly currently submitted for DETR funding

BPCF9902 European Design Manual for Pre-cast concrete
British Precast Concrete Federation

BRE99013 Advanced off-site production of steel/timber building systems to optimise productivity and widen customer choice
BRE

SCI9916 Innovative Steel-Timber Composite Components for Residential Buildings
Steel construction Institute

Projects on Pre-assembly currently funded by DETR
Projects listed in reference number order

36/8/97 Innovative application of pre-fabricated construction techniques
Contact: John Reid  Contact tel no: 01355 576200
Background: The results from this project will identify and establish effective methods of utilising prefabricated construction by researching and evaluating the success or failure of existing examples from the construction industry. With increasing involvement of manufacturers and suppliers, early in the construction process there are opportunities for increased uptake of prefabrication techniques. These techniques should considerably reduce on-site erection times and subsequent reworking compared with equivalent traditional construction techniques.

Objectives: - To establish existing best practice prefabrication techniques by researching and evaluating existing and historical work in this field; - To identify and recommend prefabrication solutions to overcome common technical risks and those that could make a positive impact on the construction process; - To establish appropriate and realistic benchmarks; - To identify and recommend appropriate innovations in existing construction practice that the utilisation of prefabrication will specifically facilitate; - To monitor and disseminate this information to the construction industry by a series of joint BRE and industry workshops throughout the project; - To provide guidance and feedback to Building Regulations.

Relevant publications/other outputs: Not known
**Innovation & strategy: the link for building services**

**Contact:** Anne King  
**Contact tel no:** 01344 426511

**Background:** A project undertaken in 1992/3 (PIF No 77640) on the uptake of research showed that there were many instances where BSRIA research has been applied in industry with significant benefit. A second phase of the work has produced a brochure for wide dissemination in industry to persuade senior executives to give more attention to research. This new project will extend the coverage of the study beyond BSRIA’s work and BSRIA members and will provide a marketing strategy to follow on from the launch of the brochure and incorporate the results of the new research. More companies will thus be encouraged to apply the results of research, so substantially increasing the return on the original research investment. The benefit will accrue, almost by definition, chiefly to companies who are not traditional funders of research.

**Objectives:**
- To promote the uptake of research by determining and publicising the conditions and organisational mechanisms used in industry to successfully apply the results of research, and the barriers to uptake;
- To identify and publicise actual benefits achieved from the application of research by industry;
- To develop a handbook giving recommendations of how to exploit research results, particularly aimed at SMEs;
- To provide training, and consultancy material for companies to enable them to develop and implement their own research and innovation strategies.

**Relevant publications/other outputs:**
- Publications: Promoting Innovation - conditions mechanisms and methodologies (BSRIA TN 5/99).
- Summaries of Outcomes and Achievements: The project produced:
  1. a report on innovation and barriers to innovation;
  2. from this, a training pack on the development of innovative strategies in building services which can be used for further training and corporate development. It is already known that one company set up a partnership arrangement following the use of the workshop pack in-house.

**A Research Technology Network**

**Contact:** Mike Smith  
**Contact tel no:** 01344 426511

**Background:** This is a proposal to set up a Technology Network of users of research results. It creates an individual, as opposed to corporate network, to increase the use of research results and provide feedback on the usefulness of research and the need for further work. Compared with the cost of research, the cost of dissemination is quite low. This Network will enable the much wider dissemination of results in order that much better value for money may be gained from investment in research whether by Government or industry. The key elements of the Network will be the creation and wide dissemination (of approximately 20,000) copies of an index of research results for the building services industry, feedback through questionnaires and workshops of the usefulness of results as perceived by the Network, and a report on how the Network might be extended to the whole of the construction industry.

**Objectives:**
- The objective of the project is to develop and run, for eventual self financing, by March 1998 a Network of users of research. The Network will be aimed at individual users of research. It will provide them with an index of research results and will develop a feedback mechanism for establishing the usefulness of existing research and the requirements for future projects.

**Relevant publications/other outputs:**
- Publications: Report available from BSRIA publications. Summary of Outcomes and Achievements: A new, live knowledge network and database of technical and research information for the building services industry, available on the World Wide Web (WWW) and including references to 100,000 items of building services information. Full text copies of all of BSRIA’s recent publications are included, bringing recent DETR research to all who access the database. The database is currently available to all BSRIA member companies, and a number of other companies who joined the initial pilot scheme. We have found that it is a very attractive tool for consulting practice librarians, but uptake from engineers themselves is slower. Three additional modules (research alerts, member database, defects database) were developed during the research and available during the pilot study. However following the low use of them at that stage, they have been withdrawn for the time being. Also developed but not yet fully tested is the "What's New" module which allows searchers to easily determine new items that have been added to the database.
**Prefabrication & pre-assembly of building services**

**Contact:** Mike Smith  **Contact tel no:** 01344 426511

**Background:** Removing specific portions of the building services assembly process to a controlled environment away from the construction site can minimise project labour costs, reduce construction times and improve installation quality. The labour productivity of building services installation work on site is lowered by interference with other trades, problems of resource programming, access and congestion. A site study by Crown House Engineering Ltd (CIBSE Journal September 1995) showed that installation cost savings of 20% are achievable by off-site assembly of distribution systems. BSRIA report 60807/1 "Opportunities in Prefabrication" (1991) estimated that the UK market for prefabrication of building services is worth £135 million. However, 91% of building companies interviewed at that time identified a requirement to broaden the scope of building services currently prefabricated and pre-assembled. Prefabrication and pre-assembly were specifically mentioned in the Latham Report "Constructing the Team" as being key elements in improving the performance of construction projects. The scope for prefabrication and pre-assembly of building services is enormous. The opportunities for prefabrication need to be thoroughly investigated and evaluated.

**Objectives:**
- To produce guidance aimed at building services engineers and project managers that will explain how, and for which applications prefabrication and pre-assembly of building services can produce more economic installations.
- To produce costed examples of beneficial prefabricated/pre-assembled solutions.

**Relevant publications/other outputs:** Report available from BSRIA publications

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**Uptake of productivity improvements**

**Contact:** Glenn Hawkins  **Contact tel no:** 01344 426511

**Background and Objectives:** This project comprises detailed studies of various innovative productivity improvements following the BSRIA report ‘Improving M&E site productivity’ (1997). It provides specific, measured results from four live construction projects.

**Relevant publications/other outputs:** Several reports including: Rowe-Roberts, A. & Hawkins, G. 2000, Uptake of productivity improvements – Feedback from first-run studies on the Stansted Airport terminal extension project, 19 Pages, BSRIA, Old Bracknell Lane West, Bracknell, Berks RG12 7AH.

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**Innovative M&E Installation**

**Contact:** Mike Smith  **Contact tel no:** 01344 426511

**Background:** BSRIA's recent 'Improving M&E Site Productivity' report suggested that a major contributory factor for the poor performance of the UK's M&E trades was the reluctance to embrace innovative installation procedures. In contrast, the project found that other countries are maximising production through the use of improved installation procedures by adopting innovative techniques. The adoption of such new techniques are essential if the UK M&E industry is to maintain its international competitiveness. Public funding is required to identify, highlight and promote the adoption of improved M&E installation techniques by all sections of the industry to overcome conservative attitudes. Manufacturers claims are often treated with a great deal of scepticism by consultants and contractors and the benefits of change are not always apparent. As an independent research association, BSRIA can help the whole M&E industry to work together to provide a better service for its clients.

**Objectives:** This study will improve the productivity of M & E contractors by:
- Identifying M&E installation techniques used outside of the UK (or not in common use in the UK) that have the potential to improve site productivity.
- Highlighting where these new techniques can be used to maximise site production.
- Assessing the barriers that may restrict the use of those innovative systems and techniques in the UK.
- Producing technical & cost/benefit analysis.
- Disseminating the findings of the work.

**Relevant publications/other outputs:** Not known
### Optimised use of standardisation, pre-assembly & modularisation in construction

**Contact:** Now Ann Alderson  **Contact tel no:** 020 7222 8891

**Background:** There have been many recent developments in construction design, materials and methods manufacturing techniques, information exchange and procurement methods. Opportunities to use these new technologies are now available to make standardisation, pre-assembly and modularisation viable construction options and effective parts of the construction process. Projects which satisfy individual client needs will be faster and easier to build, of the highest technical and aesthetic standard, and provide value for good money. At this stage, the benefits to be gained from the use of standardisation, pre-assembly and modularisation are most likely to be achieved rapidly through client/procurement initiatives.

**Objectives:** The objective is to provide clients and procurement organisations with detailed guidance and checklists, which they and their principal advisors can use to implement of standardisation, pre-assembly and modularisation, and obtain maximum advantage from them. The guidance will cover the preparation and analysis that are required from inception, through conceptual design, to formulating the project brief, and taking decisions about procurement strategy, and how to achieve the early involvement of contractors, manufacturers and suppliers, and the standardisation of electronic data exchange.

**Relevant publications/other outputs:** Report available from CIRIA publications. Various journal papers

### Clients' toolbox for demonstrating optimised use of standardisation & pre-assembly

**Contact:** Now Ann Alderson  **Contact tel no:** 020 7222 8891

**Background:** The earlier, first phase, of the collaborative research was CIRIA Research Project 532 which identified how standardisation, pre-assembly and modularisation can be used to optimise production conditions, minimise on-site work and use standard products and systems to achieve unique projects more efficiently. In addition to data gleaned from interviews, workshops of experts and site visits, lessons have been identified from other cultures such as the automotive, electronics, power and aerospace industries and from other countries such as Japan, USA and the Netherlands. It has resulted in a high-impact leaflet, entitled Snapshot, a CIRIA Funders Report (FR/CP/55) and the open publication Report 176 is soon to be published. CIRIA proposes to adopt partnering for this next phase in order to maximise the effort and minimise the cost and time of the research. CIRIA's Research Contractor for each of the two previous phases of the work is a consortium of Laing Technology Group and Loughborough University. The consortium won both contracts in open competition and they have developed a close working relation with CIRIA and with the Steering Groups for these projects (See Supporting Information, below). They are not only 'up to speed' – which an alternative contractor would not be – but as there would be a high probability of their being appointed if we were to follow a competitive procurement system there would be a high risk of wasteful effort by many organisations. As with the previous project CIRIA will collaborate with the CRT to ensure an effective industrial input and appropriate focus is maintained. It is anticipated that CRT will make a significant financial contribution both in cash and in kind. The Steering Group needs to have a balanced representation of the relevant professions and industrial interests. This has been achieved to good effect on the previous projects (P1319/RP532 and P1363/RP579). The Steering Group will therefore include a broad range of client organisation representatives (including CRT, CCF, etc.), architects, surveyors, engineers, contractors and specialist suppliers.

**Objectives:** Much wider appreciation of the advantages that can be gained from the appropriate application of SP&M to construction projects. Demonstrate that the Toolbox, developed in the earlier project (P1363/RP579), can be used effectively to improve construction projects in terms of productivity, predictability, quality and speed to provide better value for money. Use the feedback from the experience of detailed practical application of the Toolbox to refine the procedures and techniques. Prepare the Toolbox in the form of a user-friendly electronic system (CD-ROM or equivalent) for ready application in design offices by all members of the professional team.

**Relevant publications/other outputs:** Toolbox available from CIRIA. Journal papers eg ECAM 2001. Also Croner Management Guide insert & periodical
### Re-engineering timber frame affordable house construction: demonstration project

**Contact:** Geoff Pitts  
**Contact tel no:** 01494 563091

**Background:** The Latham report highlights the challenge to the construction industry of increasing construction project value through achieving a real cost reduction of 30%. Clearly change on this level cannot be achieved without some structural change to the construction delivery process. The feasibility study to re-engineer the timber frame construction process (PIF 219) identified 3 core processes, i.e. product design; customer development and order fulfilment. By implementing a full scale re-engineering study, it will increase the overall competitiveness of timber frame manufacturers and enable new firms to enter the market. It will also put existing research projects into practice such as process maps (from PIF 219), world wide best practice (PIF 213) and benchmarking framework (PIF 214).

**Objectives:** - To set new world-class benchmarks for construction from the application and demonstration of re-engineering principles applied to the timber frame delivery process targets include: - reduce cost by 30%; - reduce time by 20%; - reduce reported site defects by 50%; - meet all existing performance base criteria.

**Relevant publications/other outputs:** Publications: Client Information pack ; "Timber frame: Re-engineering for affordable housing Seminars: Presentation and debate about timber frame technology ; Four one day workshops with Amphion Consortium ; Representatives from 17 different Housing Associations TRADA Seminars Bradford April 99, Warwick April 99, Edinburgh April 99, AGM May 99 Mini-seminars to 11 supply chain companies Conferences: Cost E5 conference - Delft (Netherlands) October 1998 Continuing Professional Development (CPD): RAIS CPD seminar Aberdeen and Dundee in January 2000

### Innovative components from UK timber resources

**Contact:** Martin Milner  
**Contact tel no:** 01494 563091

**Background:** There is a need to encourage exploitation of UK sawn timber and panel product resources, research is needed to identify market need and product types for prototype development.

**Objectives:** The main objective is to undertake techno-economic assessments of engineered timber composite beams using UK timber resources and panel products and to publicise the findings. The project will seek to identify and optimise potential benefits and innovative potential in order to establish a basis for design and development.

**Relevant publications/other outputs:** Report available from TRADA publications

### Factory pre-fabrication & construction: demonstration project

**Contact:** Geoff Pitts  
**Contact tel no:** 01494 563091

**Background:** The anecdotal benefits posited of factory prefabrication are widespread; from improved quality, better tolerances, and zero defects, to construction time certainty and improved site safety. Latham cites Stanhope's interest in extensive use of prefabrication. It is also suggested that acceptance of prefabrication opens the door to other process improvements, such as sequencing, Health and Safety benefits, removing interdependencies and facilitating a JIT regime. However, there is little hard empirical evidence that this is the case and many construction projects still contain large work elements that are site based. Research is needed into the real benefits of off-site prefabrication, that can identify tangible benefits to the client and construction design team.

**Objectives:** - To provide tangible evidence in the form of a demonstration project, as to the benefits associated with using factory prefabrication, using time, cost, quality and client satisfaction, as performance indicators. This will be in the form of case study material demonstrating foundation, wall, floor, roof, services and external cladding prefabrication.

### A sustainable development centre (Zethus Centre) for the housing market

**Contact:** The Palmer Partnership  
**Objectives:** To create a centre of sustainable development for the dissemination of construction best practice in the affordable and speculative housing markets. To enhance existing best practice material using information generated and monitored from a number of live construction projects implementing tried, tested and developing technologies, processes and management techniques.  
**Relevant publications/other outputs:** Club of innovators (Amphion Consortium); a best practice portfolio for housing construction (collation of existing information plus case study material on five live projects) – print/web and CD: construction and operation of a Sustainable Development Centre: workshops and seminars

### Performance specification for pre-engineered modular construction

**Contact:** Mark Lawson **Contact tel no:** 01344 23345  
**Background:** Modular construction is an innovative and versatile form of construction in which pre-engineered modular or volumetric units are manufactured in a factory and are installed on-site. This form of construction is often used for hotels, student residences and fast food restaurants, where speed of construction, reliability of performance and installation of services and facilities are essential. The Government have recently announced an initiative towards affordable housing, and this proposal addresses the application of modular construction to residential buildings of medium-rise, particularly in inner city areas. Modular construction offers considerable benefits in this sector which will be explained in this proposal.  
**Objectives:** - To review performance requirements for multi-occupancy dwellings; - To prepare outline performance specification for modular buildings; - To carry out design studies and whole life assessments; - To prepare project report and industry standard; - to publish a detailed performance specification for modular steel construction in residential buildings which will act as an industry-standard for clients, designers and manufacturers.  
**Relevant publications/other outputs:** Report available from SCI publications.

### Design guide & innovation of modular units

**Contact:** Mr D G Brown  
**Contact tel no:** 01344 23345  
**Background:** Cold formed steel (CFS) load bearing panels can be assembled together to form larger, often self-contained load bearing elements. These prefabricated units take the generic name ‘modules’, because they are re-locatable, are often standardised in size and construction and identical units of accommodation can be replicated within a single development. There are now a number of ‘high profile’ examples of this form of construction. However, there is currently little independent design guidance available for architects and this document would provide some of the essential information to enable them to undertake the design of these elements and to understand the advantages and principles associated with their usage.  
**Objectives:** - To prepare a design guide on the use of cold formed steel in prefabricated modular units for housing, other low rise buildings, and as units within high rise buildings. The guide will review the production methodology aspects, and opportunities for new connection techniques. The guide will be presented in a form suitable for use by architects and those responsible for procuring these buildings.  
**Relevant publications/other outputs:** Report available from SCI publications.

### Good practice for small builders

**Contact:** Bill O'Neill **Contact tel no:** 01923 661000  
**Background:** The UK construction industry is comprised of mainly small companies, most of who do not read the technical press or belong to a trade group to which information can be directed. It has therefore been difficult to transmit to this group the wealth of technical information generated by BRE in a format suitable for use by these small companies.  
**Objectives:** To provide over 30 monthly feature articles providing technical advice relating to good practice in construction and defects avoidance suitable to the small builder. These articles to be published in the magazine Professional Builder ( a free journal made available through trade counters of builders merchants with a circulation of over 100,000.  
**Relevant publications/other outputs:** Report available from BRE.
Innovation & best practice in flexible & modular building solutions

Contact: Alan Gilham  Contact tel no: 01923 661000

Background: There is an increasing demand for sustainable building solutions which subsequently increase the need for more adaptable buildings; reduced consumption of resources; and improved quality and performance from the industry. The social housing sector is one such area where flexibility of provision is necessary to meet the changing demands brought about by: an ageing population; the changing family size, mobility; moves into and out of home ownership; etc. Housing providers are faced with the problem of ensuring that investment decisions make the most of resources for local provision today, yet leave the flexibility for future demand? The Southern Housing Group have made the decision to consider modular housing as a solution. This project will build on: - existing commitments to invest in the application of modular buildings from the Southern Housing Group; - established expertise of modular building providers that is manufacturers such as Terrapin, etc - environmental assessment and research capability of BRE. The approach will be to provide a background study on the potential for the application of modular buildings addressing issues such as: durability, availability, quality, perceptions, cost, etc and present this in terms of market viability. The project will go on to monitor the decision making process on the project through design, procurement and construction stages, identifying the issues which affect the use or exclusion of modular buildings.

Objectives: This project will use Project 2001 as a demonstration project and will run in parallel with 3 key objectives: - To study the technical possibilities for modular buildings, reviewing the market potential, current positioning and likely trends in demand and supply of flexible buildings over the next 25+ years. - To study the development process and application of modular buildings in the context of flexible, adaptable and sustainable solutions to the changing demands of property clients. - To study specifically the extent to which modular housing can assist social housing providers with flexible housing provision to meet unpredictable future demand.

Relevant publications/other outputs: Not known

Timber sector best practice initiative

Contact: Peter Bonfield  Contact tel no: 01923 661000

Background: The Timber Best Practice Initiative will identify the current business processes and management methods used within the timber supply chain. It will analyse the success and limitations of these to identify the barriers preventing innovation and will present the opportunities for improving communication of best practice. It will identify exemplars of best practice currently operating and will initiate new exemplars. These will be presented as case studies to clearly demonstrate the benefits to others and help motivate improvement and innovation. A communications and marketing plan will be developed in partnership with the project Advisory Group (comprised of key decision makers from along the supply chain) to encourage and motivate the timber supply chain to take up and exploit best practice. This will help optimise the impact of the project.

Objectives: The principal objective of this project is to provide the timber industry and Government (through the CBPP) with a Best Practice Initiative that encourages and motivates the implementation of best practice management methods and business processes. The project will be delivered by the CTTC/TTL partnership. It additionally has comprehensive and widespread support from along the entire timber supply chain (see attached letters of support). This composition, together with the close working relationship envisaged with the CBPP PMU, will be exploited to ensure that the project is completed within the planned time frame.

Relevant publications/other outputs: Not known

Appendix 4 DETR-funded projects on pre-assembly
<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>Contact</th>
<th>Contact Tel No</th>
<th>Background</th>
<th>Objectives</th>
<th>Relevant Publications/Other Outputs</th>
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<tbody>
<tr>
<td>39/3/176</td>
<td>House wall construction for the future</td>
<td>G J Edgell</td>
<td>01782 746 476</td>
<td>The project has developed from a consultation exercise that has demonstrated that the current and future changes to the Regulations have different consequences and costs for the various parts of the building industry. The effects on builders differ dependent on their current policy, for example, those on suppliers of timber frame housing can be very different to those on suppliers of cavity walling and indeed within the latter group there are different effects depending on the current method of satisfying the Regulations. Similarly the effects on suppliers of insulating materials, structural materials, components, insurance etc all differ.</td>
<td>- To determine and encourage the use of a small range of wall forms that retain the designers flexibility of choice of structural form, ensure low risk of rain penetration, ensure overall wall thicknesses are economic, enable improved levels of thermal insulation to be achieved in a practical, buildable, acceptable way and which show genuine benefits on life cycle costs, energy usage and CO2 emissions.</td>
<td>9 page summary and detailed reports available from CERAM - However, following review of the project report it has become apparent that this project has not really dealt with pre-assembly issues, mainly concentrating on ‘traditional’ wall construction.</td>
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<tr>
<td>39/3/239</td>
<td>Transfer of advanced manufacturing technology to construction</td>
<td>Richard Barlow</td>
<td>01734 875123</td>
<td>The aim is to apply novel 'design to manufacture' knowledge based engineering technology to a 'design to order', industry such as construction. The project outlines a route for transferring proven technology between industries. It is expected that adoption of such methods will offer considerable scope for time reduction in various stages of construction, achieving better value for money, particularly by decision support at concept stage. In addition to the benefits to individual projects, it is anticipated that the UK construction industry could benefit enormously, producing better buildings, and offering a useful boost to the UK industry's drive for improved productivity.</td>
<td>- To use knowledge based engineering (KBE) to enable visualisation of design alternatives within lift manufacture, carried out with Schindler Lifts using their component catalogue. Other work in progress includes projects which demonstrate how to apply the technology in a similar way to aircraft loading bridges and aprons, baggage sorting systems and building cladding components.</td>
<td>Report available from University of Reading</td>
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<td>39/3/284</td>
<td>Rationalisation of flat slab reinforcement</td>
<td>Charles Goodchild</td>
<td>01344 762676</td>
<td>Within the construction industry there are many different views about what constitutes the most economic way of reinforcing concrete. This is especially true of reinforced concrete flat slabs where strict adherence to codes can give 60 reinforcement arrangements. Comparative studies are proposed to evaluate the benefits of rationalising reinforcement sizes and spacings, using bespoke prefabricated mats or fabric, and using different methods of punching shear provision. The work will involve producing rationalised and prefabricated layouts of reinforcement to be used in the in-situ building of the European Concrete Building Project (ECBP) at Cardington, and measuring and disseminating the time/cost benefits.</td>
<td>The primary objective of this project is to reduce the costs of flat slab construction by disseminating meaningful guidance on the rationalisation of reinforcement. The reduction of complexity, and the benefits of increased rationalisation and prefabrication will improve the quality and competitiveness of flat slabs and will have important spin-off benefits for other areas of the construction industry.</td>
<td>BCA Publication 97.376: Rationalisation of Flat Slab Reinforcement Concrete (November 2000): Best Practice Guides Seminars: BRE Cardington, 5 April 2000 I Struct E, 3 July 2000: full 200 page report available from Reinforced Concrete Council: 2 page high impact publicity document (Best Practice Guide).</td>
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<tr>
<td>39/3/285</td>
<td><strong>Tilt-up Construction</strong></td>
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<tr>
<td><strong>Contact:</strong> Mr M Southcott</td>
<td><strong>Contact tel no:</strong> 01344 762676</td>
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<td><strong>Background:</strong> Tilt-up construction of low rise buildings, where load-bearing concrete walls are cast on the ground floor slab and then tilted and lifted into position, dominates certain construction sectors in the USA and Australia. In addition, there is a growing market in concrete sandwich panels in tilt-up. The UK has proven slow to adopt this innovative, yet competitive, form of construction with potential benefits such as, thermal mass, durability, security, site safety, sound and fire resistance. The inherent conservatism of UK construction means that matters of design, construction, architecture and economics must be investigated, and adapted for the UK market. These will be disseminated through a suitable design and construction guide.</td>
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<td><strong>Objectives:</strong> The objective of the project is to undertake the necessary work to encourage the introduction of concrete tilt-up construction, including sandwich panels, into the British low rise industrial, commercial and retail building sectors.</td>
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<td><strong>Relevant publications/other outputs:</strong> CD video and report available from Reinforced Concrete Council</td>
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<td>4 page high-impact flyer</td>
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<td>website <a href="http://www.rcc-info.org.uk">www.rcc-info.org.uk</a></td>
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<tr>
<th>39/3/365</th>
<th><strong>Factors affecting the use of pre-fabricated masonry systems</strong></th>
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<tr>
<td><strong>Contact:</strong> Mr D J Harris</td>
<td><strong>Contact tel no:</strong> 01732 847947</td>
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<td><strong>Background:</strong> The history of prefabrication of masonry and concrete in UK housebuilding is one of contrasts. Precast flooring systems are widely used, precast or prefabricated walling systems are not. This study is designed to ascertain the problems that need to be solved for masonry prefabrication systems in order for them to be seen as acceptable by house builders. The issues are expected to embrace design, manufacturing, construction, economics and marketing concerns. Many are related to the use of information in the supply chain and could be addressed by the correct use of IT. Others are related to the perceptions of the product.</td>
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<td><strong>Objectives:</strong> The aims of the study are: - To identify the problems preventing the introduction and take-up of prefabricated masonry systems in the UK domestic housebuilding sector. - To develop a draft guide and specification for designers, house builders and manufacturers to enable cost effective use of prefabricated masonry systems. - To assess the viability of a European prefabricated system for a number of selected UK projects.</td>
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<td><strong>Relevant publications/other outputs:</strong> Report available from H + H Celcon</td>
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<tr>
<td>39 page Report – Pre-assembled masonry systems available from Doug Harris – 01732 886333</td>
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<tr>
<th>39/3/452</th>
<th><strong>Rationalisation in standardised construction</strong></th>
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<tr>
<td><strong>Contact:</strong> Nigel Graham</td>
<td><strong>Contact tel no:</strong> 01582 424200</td>
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<td><strong>Background:</strong> One contribution to achieving the objective of reducing real construction costs is to significantly improve site performance and productivity. To achieve this performance benchmarks must be set for the whole process and against which the effect of subsequent process change can be measured. At the present time the construction industry, unlike manufacturing, is notoriously short of such benchmarks. Indeed the culture for process performance monitoring is almost universally absent.</td>
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<td><strong>Objectives:</strong> - To reduce construction time by identification and elimination of process bottlenecks, to encourage a wider use of standardised components, to reduce necessity for re-work and to raise construction quality all within a framework of reduced cost. It is intended that the project will deliver relevant performance metrics and to exemplify the benefits of process change which though dissemination and example will diffuse through the whole of the construction industry.</td>
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<td><strong>Relevant publications/other outputs:</strong> Project terminated. Case study on the construction of the Gatwick Travel Inn is available</td>
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<td>Project ID</td>
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<tr>
<td>39/3/459</td>
<td>Systems approach to timber floor design &amp; manufacture</td>
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<tr>
<td>39/3/491</td>
<td>Development of monocoque panel systems for long span structures</td>
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<tr>
<td>39/3/507</td>
<td>Good building guides</td>
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Facilitating the benefits of technological innovation

Contact: Stephen Gregson  
Contact tel no: 01225-320600

Background: The one area in which such clients are less able to gain the benefits of innovation (not surprisingly, perhaps, since they generally lack the technical understanding) is that of the building itself - how it works, how it is designed, how it is constructed, how it performs during its life. Some notable clients such as BAA and Slough Estates have radically changed the way in which they design and procure construction projects. However, clients such as these are very experienced as construction clients, and consequently are very informed in the whole construction process. Some technical innovations have been embraced by clients, the most notable in structural engineering perhaps being the opportunity for long span office floors using cellform beams. The situation is more difficult for occasional building clients who have to rely on the advice of professionals who, themselves, may not fully understand how best to liberate the benefits to be gained from good, well-managed technical innovation in construction projects.

Objectives:  
To identify the barriers to innovation in construction projects and produce a widely read report on these barriers and how they can be overcome.  
To report on the previous use of innovation on projects - through case studies published on the internet and through M4I and the Reading Construction Forum.  
To provide guidance to clients and project managers on the use of innovation on construction projects. To circulate the reports and the knowledge obtained from the study by means of seminars, journals and via the Reading Construction Forum and M4I.

Relevant publications/other outputs: Not known

Development of decision-making tools for controlled innovation in construction

Contact: John Rogerson  
Contact tel no: 01234 750111

Background: An established method for improving the efficiency of the design of manufactured components is to include ease of manufacture and assembly as key inputs to the design process. Decision support tools have been developed to aid manufacturing design. Construction design has some similarities but some differences to product design so the justification and aim of the work is to examine the construction design process to see to what extent and how decision support tools, analogous to those used in manufacturing industry, could be applied to improve and control better the construction design process.

Objectives:  
- To analyse the consequence of design decisions. This will be done by reviewing, on a normalised basis, design change records from a number of projects. This provides generic data on the problem of design changes and their consequence. The analysis of existing briefing and design decision making processes cannot be done on historical data because of the inadequacy of records, so a briefing and design making template is used to record actions in real time. An evaluation of IT tools is being made to establish the constrains for decision making tools so that a credible scenario for a decision making tool can be devised.

Relevant publications/other outputs: Report available from University of Cranfield
Standardisation in brickwork construction

Contact: Nashwan Dawood  Contact tel no: 01642 342403

Background: In order to achieve the objectives of the research work, the following activities are being undertaken: - A literature review and study of previous and current development of brickwork systems, in Europe, USA and Asia. - The identification of current practices and the potential for proposed development. The participating partners will contribute in knowledge, case studies and information. In order to develop an industrial consensus, a wide industrial survey will be conducted using the semi-structured interviews approach. - Development of recommendations for standardised approaches to procurement, design and specification for prefabricated solutions. This includes identification of potential approaches to integrating business processes. - The measuring and benchmarking of proposed solutions. This includes cost/benefits of the proposed procedures. The cost and time savings that can be achieved through re-engineering business processes will be assessed.

Objectives: This proposal addresses the scope for improving the efficiency of construction involving standardisation of brickwork by harnessing the synergy between technological development in the area of design, fabrication, assembly and site construction technique, and business process development. The specific objectives are: - To evaluate previous and current research work in the area of standardisation and, in particular, the standardisation of brickwork; - To identify current practices and the potential for developing standardised solutions; - To identify guidelines and best practice for standardisation of brickwork; - To measure and benchmark proposed standardised procedures/products.

Relevant publications/other outputs: Website [www.sst.U0011809/external](http://www.sst.U0011809/external)

Innovation in standardised component systems in housing

Contact: James Barlow  Contact tel no: 01273 877166

Background: This project brings skilled researchers from engineering and technology management, logistics and systems dynamics, planning and regulatory policy, together with leading housing suppliers and clients. The main activities will involve developing, testing and evaluating two sets of demonstration houses. Pathfinder I will test immediate costs, benefits and barriers to component-based approaches, by introducing innovative, standardised component systems in two houses. Pathfinder II will test larger-scale applications in demonstrators in the public and private sectors. Our work will involve: - Analysis of changing housing markets, user requirements and key technical trends; - Evaluation of supply-chain management issues; - Development of evaluation framework for Pathfinder I and identification of opportunities to test innovative standardised systems, facilitation and evaluation; - Development of a route map for Pathfinder II, facilitation and evaluation; - Provision of user needs feedback to collaborators, together with supply-chain and organisational recommendations; - Development of generic technical specifications and recommendations for planning and building regulation policies.

Objectives: - To develop a component-based approach similar to that used in manufacturing and in housing industries in other countries to transform the delivery of housing in the UK; - To evaluate different technologies for component-based housing production; - To evaluate the costs and benefits of increasing flexibility to improve customer choice; - To evaluate the implications of a component-based approach for supply-chain management; - To evaluate implications of this approach for planning and regulations; - To assess the trade-offs in cost, time flexibility and quality for : traditional site-based work; the use of component systems in new site-assembly processes; and meeting customer requirements.

Relevant publications/other outputs: Not known
Standardisation & skills: a transnational study of skills, education & training for prefabrication in housing

Contact: Nicholas Gould  Contact tel no: 020 7911 5811

Background: The aim of the research is to assess how far the manufacturing-based methods in the British construction industry is influenced by existing skill and education/training structures and to suggest areas for improvement. It will: identify different forms of prefabrication and standardisation associated with different skill constellations in Britain, Denmark, Germany and The Netherlands; describe the skills (including the degree of multi-skilling), qualifications and training of all the different participants in more traditional housing construction compared with those for non-traditional forms of construction; outline the related business processes (including client/contractor/subcontractor relations) and supply chains (from design to manufacturing to assembly) and firm/project organisation. The focus is on a selection of housing association projects and a survey will be conducted of the housing associations, designers, contractors, subcontractors and operatives concerned. The project is for two years and its output is a research report/book, articles, handbooks and a summary booklet for wide dissemination through a conference, seminars and publications.

Objectives: - To assess how far the extension of manufacturing-based methods in the British construction industry is deterred through existing skill and educational/training structures. - To describe the skills, education and training of personnel at all levels involved in more traditional housebuilding construction using standardised, prefabricated components - with examples from Britain, Denmark, Germany and The Netherlands. - To assess the degree of multi-skilling entailed in traditional and innovative construction. - To identify and define the different constellations and qualities of skill in the four counties. - To draw up a skill classification matrix referring to type of process, firm and client, and recommendations on training and education requirements. - To disseminate the findings as widely as possible.

Relevant publications/other outputs: Project just finished – Final report imminent – Workshop 4/5/01 – Journal papers expected

Overcoming client & market resistance to prefabrication in housing

Contact: Martin Edge  Contact tel no: 01224 263714

Background: This proposal builds on an earliest submission to MCNS (Meeting Client Needs through Standardisation) which proposed an examination of the cultural and other barriers to prefabrication in the house-building industry. Its central premise is that, in order to optimise the efficiency and worth of new housing activity, client resistance to the introduction of greater levels of pre-fabrication and standardisation needs to be understood and overcome. The project adopts a broad definition of the ‘client’, though the primary focus is on the purchased and end use of housing. The aims of the research will be achieved in a two stage process, funding for the first stage of which is now sought. The first stage involves the development and testing of new, predominantly financial models though the resistance to pre-fabrication and housing can be eased. The second stage involves the practical, on-site demonstration of both product and process developments which can in ease market penetration of, and confidence in, pre-fabrication and standardisation. The first stage is the primary component which requires research funding. The second stage is a near-market, developmental phase which, it is hoped, will be carried out with industrial sponsorship.

Objectives: The primary aim of the first stage of the project is to construct and test models for the procurement of housing which will facilitate the introduction of greater degrees of standardisation and pre-fabrication. The construction of such models involves the investigation of socio-cultural and economic resistance to pre-fabrication amongst a widely defined client group. The main focus will however be on the ultimate ‘consumer’ of housing and arrangements for the valuation, capital funding, maintenance and reconstruction of homes exhibiting different degrees of pre-fabrication. The primary aim of the second stage of the project is to demonstrate the efficacy of the above models through the construction and marketing of demonstration housing. This process will involve a close collaboration between parties to the project. In particular it requires the joint action of the construction and manufacturing sector with the financial sector. A successful outcome would show that radical design and engineering in housing is not necessarily precluded by client resistance, as long as the nature of the home as a capital investment is addressed. A role of the Technical Forum is to encourage the adoption of stage two demonstration projects as a market-let, or near-market enterprise, without the need for further Research Council or DETR funding.

Relevant publications/other outputs: Not known
Pre-assembly in construction

Appendix 5

Pre-assembly Patents (1990-2000)
<table>
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<th>Patent No.</th>
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<td>Prefabricated concrete element for building a civil engineering structure having an arched wall</td>
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<td>Melo Ferreira Alberto Antonio (Fr); Barbier Laurent Jean (Fr)</td>
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<td>Oct-00</td>
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<td>KR189544Y</td>
<td>A multi-functional panel used in construction</td>
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<td>WO9960223</td>
<td>Prefabricated finishing module for the construction of building construction and building constructions obtained thereby</td>
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<td>Luchini Claudio (It); Vallacqua Giulio (It)</td>
<td>Studio Arch Claudio Luchini (It); Luchini Claudio (It); Studio 3gv Progetti Giulio Val (It); Vallacqua Giulio (It)</td>
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<td>D424,207</td>
<td>Prefabricated Building</td>
<td>Jun-99</td>
<td>Tasse; Sylvain (3182 Gaetane, Laval, Quebec, Ca)</td>
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<td>DE19653633</td>
<td>Structural prefabricated building design</td>
<td>Jun-99</td>
<td>Kaiser Karl (Ch); Fritzsche Albert Dr Ing (De); Kissingdorfer Wolfgang (De)</td>
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<td>US6134849</td>
<td>Prefabricated self-supporting pannedled structure system</td>
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<td>Holler; Max Michael</td>
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<td>Barbier; Laurent Jean; Melo Ferreira; Alberto Antonio Samflo (Fr)</td>
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<td>US6151857</td>
<td>Prefabricated composite construction for internal and/or external building-walls</td>
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<td>Raschke; Gabriele</td>
<td>Pieces, Llc</td>
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<td>US6151843</td>
<td>Prefabricated wall panels connecting system</td>
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<td>Weaver; Gary L. (Ephrata, Pa); Martin; Robert G. (Narvon, Pa); Weaver; Jan L. (Kissimmee, Fl)</td>
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<td>JP11036323</td>
<td>Foundation construction of prefabrication type steel frame building</td>
<td>Feb-99</td>
<td>Osaka Masamitsu; Jo Ken</td>
<td>Yokogawa Bunsuiji/Kk</td>
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<td>US6167671</td>
<td>Prefabricated concrete wall form system</td>
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<td>Wilson; Steven D.</td>
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<td>US6073410</td>
<td>Structure and formulation for manufacture of prefabricated buildings</td>
<td>Oct-98</td>
<td>Schimp; Michael J. (San Diego, Ca); Harrel; Marcus J. (Chula Vista, Ca)</td>
<td>Eco Building Systems, Inc. (Chula Vista, Ca)</td>
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<td>US6123888</td>
<td>Method of manufacturing post tensioning prefabricated building</td>
<td>Jul-98</td>
<td>Smith; Rodney I.</td>
<td>Easi-Set Industries</td>
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<td>US6098364</td>
<td>Prefabricated outer wall structure with stress rupture resistance</td>
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<td>Liu; Hsin-Chin</td>
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<td>US6006480</td>
<td>Low cost prefabricated housing construction system</td>
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<td>Rook; John G. (33 Greenview Ct., San Francisco, Ca 94131)</td>
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<td>US6120208</td>
<td>Prefabrication type high level road structure and construction method thereof</td>
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<td>Bidimensional prefabrication system for civil and industrial buildings made up of modular equipable walls having a wood load bearing structure relevant fixtures for the realization of the prefabrication components, and prefabrication components</td>
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<td>US5921043</td>
<td>Prefabricated, enclosed building</td>
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<td>Mcdonald; Harley C. (Omaha, NE)</td>
<td>Composite Structures, Inc. (Omaha, Ne)</td>
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<td>US5953864</td>
<td>Prefabricated modular concrete foundation wall system and methods of constructing prefabricated modular concrete foundation wall systems</td>
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<td>Beck; William G. (Midland, Mi)</td>
<td>Rapid Wall Systems (Gladwin, Mi)</td>
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<td>US6105326</td>
<td>Building, comprising prefabricated components</td>
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<td>Schmidt-Lutz; Rolf</td>
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<td>EP0727277</td>
<td>Pre-assembly and pre-treatment of sections for window or door frames</td>
<td>Aug-96</td>
<td>Thoemmes Wolfgang (De); Anker Horst (De); Brosius Detlef (De); Klein Alfred (De); Konz Peter (De); Thoemmes Heinz (De)</td>
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<td>US5950374</td>
<td>Prefabricated building systems</td>
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<td>Gromat; Johannes (Hill End, Au)</td>
<td>Leftminster Pty Ltd. (Queensland, Au)</td>
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<td>US5471804</td>
<td>Building system using prefabricated building panels and fastening components used therewith</td>
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<td>US5459966</td>
<td>Prefabricated bathroom walls</td>
<td>Jun-94</td>
<td>Suarez; Miguel A. (11038 Green Line Way, Orlando, Fl 32837); Avila; Gilberto (5445 Nokomis Cir., Orlando, Fl 32839)</td>
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<td>US5964067</td>
<td>Prefabricated building elements, and process for producing the same and for building with them</td>
<td>Apr-94</td>
<td>Lehner; Wolfgang Robert (Feldgasse 1, A-1080 Vienna, At); Lehner; Annemarie (Feldgasse 1, A-1080 Vienna, At)</td>
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<td>US5448862</td>
<td>Prefabricated component for building staircases</td>
<td>Mar-93</td>
<td>Candiracci; Angelo (Via Rosciano 16, 61032 Fano (Prov. Of Pesaro), IT)</td>
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<tr>
<td>FR2638180</td>
<td>Method for construction of individual dwellings</td>
<td>Apr-90</td>
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<td>Hantute Guy (Fr)</td>
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Pre-assembly in construction

Appendix 6

Summary Bibliography
Appendix 6  Summary Bibliography

Full bibliographies covering the subject have been published, for example in CIRIA’s Standardisation and Pre-assembly report (1999) and Off-site fabrication (1999). Summary bibliographies have also been produced in various places including CBPP’s website and Croner’s Project Management review. Listed here are the key texts on the subject that are readily available. Most of these are recent, however a few older texts have been added especially where they provide a useful review of historical issues.

Construction Management and Economics – Special Issue: Tribute to Steven Groak

Standardisation & pre-assembly - client’s guide and toolkit
Gibb, A G F, CIRIA, 2000, Construction Industry Research and Information Association (CIRIA), 6 Storey's Gate, Westminster, London SW1P 3AU, UK

Building innovation: complex constructs in a changing world
Gann, D.M., 2000, Thomas Telford, Heron Quay, London

Standardisation and pre-assembly – adding value to construction projects

Offsite fabrication – prefabrication, pre-assembly and modularisation

Prefabrication and pre-assembly – applying the techniques to building engineering services
Smith, M (ed), 1999, Building Services Research & Information Association (BSRIA), Old Bracknell Lane West, Bracknell, Berkshire RG12 7AH, UK

Open industrialisation in building

Innovation in Japanese prefabricated house building industries

Modularization/Pre-assembly – benchmarking implementation results
Various, 1994, Publications Manager, Construction Industry Institute, The University of Texas at Austin, 3208 Red River, Suite 300, Austin, Texas 78705-2650, USA

Prefabricated Modules in Construction

Precast Concrete Framed Buildings
Elliott, K et al, 1992, British Cement Association, Telford Avenue, Crowthorne, Berkshire RG11 6YS, UK

Constructability improvement using prefabrication, pre-assembly and modularisation
Tatum, C, 1987, Publications Manager, Construction Industry Institute, The University of Texas at Austin, 3208 Red River, Suite 300, Austin, Texas 78705-2650, USA
Pre-assembly in construction

Appendix 7

Pre-assembly: Professional Journal Review
<table>
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<tr>
<th>Title</th>
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<th>MB</th>
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<th>M&amp;E</th>
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<td>A bridge in time</td>
<td>New Civil Engineer</td>
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<td>Kvaerner, Jackson Civil Engineering</td>
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<td>A flexible environment</td>
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<td>Williams E</td>
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<td>Joseph Rowntree, Westbury, SPRU, Sheffield Hallam University, Bartlett School</td>
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<td>A position of trust</td>
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Appendix 7

Pre-assembly Professional Journal Review
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