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Current Practice and Potential
Uses of Prefabrication

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Prepared for :
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New and Improved Technologies and Techniques

Defining the Sustainability of Prefabrication and Modular Process in Construction

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Interim Report

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Executive Summary

This is the first output of a DTI funded project “Defining the sustainability of prefabrication and modular process in construction” (customer ref. 36/08/328 cc2114). The report is drawn from a desk study of prefabrication in the UK and seeks to give context to the current use of prefabrication techniques.

Prefabrication, be it full volumetric application or based at component level, need only affect the construction process and not the end-product. The use of prefabrication offers an alternative route to procuring a building, which may offer opportunities for benefits due to the change in the construction process. The benefits of using prefabrication include:

- Higher quality products for clients;
- Improved productivity and profitability for contractors;
- Environmental benefits associated with its use.

This report outlines the history of prefabrication in the UK, as recent history (1960-1975) has provided the context by which prefabrication is perceived. Problems with large panel system built housing from this era has left a lasting image problem for prefabrication.

The report considers the range of systems available currently in the UK and the benefits that can be achieved through implementation. Recent studies into the state of construction, particularly the Egan Report in 1998 have presented construction with a challenge to innovate in its practices and improve its performance. The benefits of good application of prefabrication are such that it could potentially help construction meet the targets set by Egan. This has raised the level of interest in prefabrication techniques and studies are underway to assess its potential.

Barriers to prefabrication are presented from the perception resulting from past mistakes. Independent assessment coupled with better information about system capabilities is needed to overcome this.

The sustainability characteristics of prefabrication can qualitatively be presented as being generally favourable when compared to traditional site procurement, but, the quantitative performance remains to be defined. This will be the focus of the remainder of this project.

Prefabrication has the capability to make a difference within the UK construction industry in economic, social and environmental terms. It is important that how much of a potential difference it can make is established so that appropriate development can be implemented.

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1. Introduction

This report is the first output of a DTI funded project “Defining the sustainability of prefabrication and modular process in construction”. This report is drawn from a desk study of prefabrication in the UK and seeks to give context to the current use of prefabrication techniques.

Prefabrication, be it full volumetric application or based at component level, need only affect the construction process and not the end-product. In principle identical buildings can be equally procured through traditional or prefabrication routes, technology need not present any particular barriers. The use of prefabrication should merely offer an alternative route to procuring a building, which may offer opportunities for maximising value for all concerned.

The benefits of successfully using prefabrication systems as opposed to traditional systems include:

- Quicker build times on site;
- Better ability to build to optimum cost;
- Higher quality end products due to closer factory control of part of the process.

The Egan Report has provided impetus for the UK construction industry to consider the way in which it operates and specifically the opportunities that exist for improving the process and delivering a higher value product. Prefabrication is one technique offering the construction industry opportunities for working towards meeting the Egan targets, and as such has become one of the issues considered by the Movement for Innovation and the Construction best Practice Programme.

Improving the value to clients has led to consideration of the whole life performance of buildings in which cradle to grave assessments of the costs of building are taken into consideration at the design stage. This type of assessment is now a recognised part of PFI procurement exercises. This long term view of development is also coming to the fore in the drive for sustainable development and demonstrating the sustainability of a project requires the application of Life Cycle Assessment tools. For a full understanding of the benefits of prefabrication this type of technique needs to be applied in its assessment.

Techniques for prefabrication are well established in the UK and there are currently examples of prefabricated components being used which are considered to be a “normal” part of the process. However, the image of prefabrication, particularly in the housing sector, is still strongly tarnished by some of the past mistakes that have occurred. To allow successful application of prefabrication these past mistakes need to be recognised and in particular the following addressed:

- Quality – previous lack of quality has led to the perceived reduction of value associated with prefabricated buildings;
- Attention to detail – poor detailing in the past has led to technical problems and a general perception of poor value;
- Life cycle performance – failure to consider the practicalities and costs associated with maintaining these buildings had led to some prefabricated buildings becoming difficult to maintain.

The potential for prefabrication if delivered correctly is to allow more client choice and involvement, particularly in the case of housing where a variety of different features and systems can be realised from manufacturers. For the construction industry prefabrication allows the problems associated with the traditional shortage of skills to be avoided. The drive for higher quality, more sustainable construction solutions that are delivered at cheaper cost provides prefabrication and modular construction with an opportunity to establish itself as a trusted solution, however, the benefits need to be clearly demonstrated for industry to act.

2. History of Prefabrication in the UK

2.1 Origins of Prefabrication in the UK

Major activity in mass prefabrication for system building date back to the early part of the twentieth century. There are many examples of its use however, which predate this such as the first Iron Bridge in the UK, which was built at Colebrookdale in 1779. Other early activity includes the export of houses, churches and hospitals to the colonies in the middle of the nineteenth century.

The impetus for developing mass prefabrication techniques occurred after the First World War when the necessity for the provision of new housing could not be handled by the trades system and traditional building methods. The almost complete halt to programmed building during the two World Wars and the destruction of existing buildings during the wars, lead to a greater demand for buildings in the periods of reconstruction following both conflicts. Even before the First World War, the housing standards were extremely poor for many people. There was therefore a great existing need to replace the sub-standard properties in each authority and to increase the number of properties available for rent. The low production and destruction of the war years was therefore imposed on a pre-existing context of shortages in housing provision.

The ability of what was left of the house building industry to respond to these demands was very limited. There was an inevitable shortage of both traditional materials and skilled personnel after both wars. It was recognised that the combination of scant resources and the urgency and volume of the need could not be satisfied by traditional methods. These circumstances created the climate for reconsidering the procurement and construction of buildings to service the need.

2.2 1914-1939

The problems of dealing with post-war building had been recognised by the government at an early stage during the first World War. The formation of a Ministry of Reconstruction in August 1917 resulted from discussions on the task of rebuilding. The Ministry was given the brief to:

“To consider and advise upon the problems which may arise out of the present war and may have to be dealt with on its termination”

The main need was initially perceived to be to find an alternative to bricklaying. The development of concrete for use in walling therefore, occupied much of the early attention. Very few of the techniques arising at that time involved prefabrication. It was

only in the field of steel housing, in certain types of imported Scandinavian houses, and in a concrete house, that prefabrication was significant.

Prefabrication following the First World War had virtually ceased by 1928. It had not managed to consistently compete with traditional building. Its main contribution had been to provide a small additional number of houses during this period. These houses would probably not have been built using traditional methods due to material shortages. None of this technology was transferred into traditional construction and there were no significant changes in approach that would move the industry forward. Essentially it had been an episode that although helpful in terms of the number of houses built remained detached from the approach to building used by the rest of the industry and therefore had no long-term impact on construction at that time.

2.3 1939 onwards

Following the Second World War there was a shortage of housing stock due to destruction by bombing and the lower priority given to new building works during the hostilities. There was therefore a need for the deficit to be reduced as quickly as possible. The political pressures to provide homes for the soldiers returning from abroad were perhaps only matched by the pressures to find employment for them. Many of the factories that had been in full production for the war effort were now moving to a care and maintenance basis since the demand for armaments was reduced to a fraction of full capacity. The opportunity presented itself to address both problems together by adapting the production in these factories to prefabricate parts of houses that could then be quickly erected on site. This required some creative thinking and design work since the war output of the factories was far removed from the traditional materials for housing (i.e. timber and brickwork).

In September 1942 the Minister of Health, the Secretary of State for Scotland and the Minister of Works appointed the Interdepartmental Committee on House Construction. It was presided over by Sir George Burt and became known as the Burt Committee. The committee was charged with considering materials and methods of construction suitable for the building of houses and flats, having regard to efficiency, economy and speed of erection. From this consideration recommendations were made for post-war practice.

The programme of work agreed was as follows:

1. To investigate the alternative methods of house construction used in the inter-war years, and to advise on such methods as might be capable of application or suitable for development in the post-war period.
2. To consider the *application* of methods of prefabrication to house building.
3. To examine any proposals put forward for new methods of construction.
4. To consider proposals made by the Study Committees of the Directorate of Post-War Building, Ministry of Works, in their relation to house construction.
5. To make recommendations for the carrying out or testing of forms of construction by field research or experiment.

The reports from the committee prepared the background for further development of prefabrication. Most of the new systems however, started from scratch rather than developing any of the inter-war systems.

In October 1944, The Housing (Temporary Accommodation) Act was passed. It authorised the government to spend up to £150,000,000 on the provision of temporary housing.

Between the years of 1945-48, around 157,000 temporary houses were manufactured, or imported, and erected. This is significantly less than the numbers expected by the programme. This gap between expectations and actual provision has contributed to the perception of a poor programme.

2.4 Timber Systems in the UK

System-built timber frame dwellings were gradually introduced into the United Kingdom in the 1920s as a response to the shortage of labour in the aftermath of the First World War. The external walls of the early systems were typically either heavy-framed panels or virtually solid timber planking, directly clad with timber boarding.

Systems with timber stud framed external walls were built between 1927 and 1941. The timber frame generally consisting of single-storey height panels (for the London County Council Timber system, the panels extend to two storeys). The frames were usually overlaid with a breather type membrane of building paper or bituminous felt, and then clad with timber boarding nailed directly to the frame. The frames were lined with fibreboard or plasterboard, possibly over timber boarding. There was rarely any insulation between the studs.

The work of the Burt Committee led to an increase in the number of non-traditional properties being built in the UK. This included timber frame houses, which were imported in significant numbers.

The shortage of timber led to forms of rationing with standards limiting section sizes and where timber should be used in house construction. This meant that timber sections of systems built after 1945 were often smaller than had been used before and even during the Second World War. Innovations introduced after 1945 included the use of separate claddings (commonly of brick, backed by a cavity), stressed skin panels and systems in which whole accommodation units were fabricated in the factory and then assembled on site.

The rationing continued until controls were lifted in 1953. Timber has always been easy to form into panels and without the shortages and the rationing it is likely that prefabricated timber systems would have been more prevalent than was the case.

Between 1945 and 1965, some 20,000 timber frame dwellings were built, all using timber stud construction. From 1966 to 1975, system-built housing was widely used in the

public sector. Many timber frame systems were developed during this period, most of which were of essentially similar construction.

Overall, more than 80 000 timber frame dwellings were built, using over 30 main systems. They are generally characterised by external wall cladding that is separated from the loadbearing timber frame panels, either by a cavity at least 50mm deep or by timber battens.

2.5 Large-panel high-rise residential buildings

There was a major push in the late 1950's to provide increasing numbers of housing units within a very short space of time and making the maximum use of restricted site space. These constraints and cost limits lead to the introduction of Large Panel Systems (LPS) Construction in the UK using existing technology first developed in Denmark in 1948. One such system was the Larsen Neilsen system and Taylor Woodrow - Anglian Ltd were the United Kingdom licensees.

The first structure erected in the UK of this type was for the London County Council in 1963. When it came into being in 1965 the London Borough of Newham commissioned nine, twenty-two storey Larsen Neilsen blocks.

The construction of the now infamous Ronan Point block was started on the 25 July 1966 and it was the second to be completed and was handed over on the 11 March 1968. An explosion occurred (5.45 am Thursday 16 May 1968) four floors from the top which lifted the top four floors momentarily while the, now unrestrained, flank wall was blown out. When the load from the top four floors returned the supporting walls were no longer present to offer any resistance and hence the weight of some of the upper construction descended through a storey height before impacting on the next lower floor of the south east corner. At the time of the collapse only eight flats remained vacant at the time of the explosion and it was fortunate that four of these were situated in the south-east corner which collapsed.

Most of the LPS dwellings were built in the 1960's. Following the collapse of Ronan Point in 1968, the then Minister of Housing and Local Government instructed local authorities in August 1968 to appraise the structural design of existing and proposed LPS blocks. The programme was intended to reduce the probability of progressive collapse in the event of the loss of load-bearing elements. This resulted in a nation-wide programme of assessment and the strengthening of many existing LPS blocks, together with the review modification of the design of the many LPS blocks then under construction.

There is now concern for the durability assessment of large panel system built dwellings is usually an evaluation of the likelihood of corrosion of any embedded steel reinforcement, particularly for cladding panels forming the external envelope. This is likely to be the main form of deterioration in these structures, although others are possible.

Many of the systems have also suffered from water penetration as the jointing materials aged. Poor thermal performance has also been a feature of many of these dwellings. The frequent consequence of condensation at cold bridges led to concern and dissatisfaction among tenants. Many of the problems that have occurred with these systems are a result of poor workmanship rather than design, they have however left a perception with many of prefabrication being associated with poor quality buildings. The specific problems at Ronan Point were not all related to the form of construction. The publicity however has been closely associated with the method of building and has again contributed to a negative view in some quarters of prefabricated forms of construction.

2.6 Non-Domestic Applications in the UK

Non-domestic buildings have a wide variety of performance requirements, depending on their function, that need different levels of complexity in the construction process to achieve. The size, shape, form and fabric of non-domestic buildings is more diverse than that found in UK housing. The use of prefabrication technology is well established for some applications, and the scope for future application is considerable.

The provision of schools in the UK has a long track record of using prefabricated products. It has been used for school building since the end of the Second World War, when the pressure to restore the country to some of normality was challenged by the shortage of resources and skilled labour. The Hertfordshire schools programme was an outstanding example of a programme which used prefabrication technology to meet the local pressures from the expansion of London and the establishment of post war new towns (Hatfield, Hemel Hempstead, Welwyn Garden City, etc) that were driving the need for schools. Particular systems of prefabrication developed for school construction in the 1950's include the Intergrid system (using precast reinforced concrete columns and beams to form the structure) and the CLASP system (based on lightweight steel). The Intergrid system in particular was widely used, and many school buildings that were erected with this system are still providing satisfactory school buildings today.

Commercial clients perceive the construction time of new outlets as a delay in their ability to trade and as such apply pressure for faster build times. Fast track construction schemes have been tried by commercial clients for a number of years to reduce time spent developing new outlets. Prefabrication has been identified by many as a way of achieving faster completion on commercial premises. McDonald's Restaurants use prefabrication technology to build their new outlets, recently they set their record of a completed outlet being built and open for business within 13 hours of starting construction on prepared ground works. This has considerable commercial implications for business and a range of clients from hotels to retail outlets are using some form of prefabricated procurement.

Other specific uses of prefabrication technology have included the prefabrication of heating and cooling plant and other building services. Traditionally the installation of building services is a time consuming and intensive part of the construction of a commercial building, factory manufactured modules can save considerable site time.

3. Current Prefabrication Applications

3.1 Systems Available

Currently the UK construction industry is applying prefabrication to a wide variety of forms and applications. This ranges from the simple prefabricated site hut, which has been a long established application, up to volumetric units that can be delivered to site to integrate into the structure of the building. More difficult to define are the prefabricated components that are available and can be combined to become part of the structure, standard components are available as well project specific components. Types of prefabrication approaches that can be used include:

- Volumetric systems;
- Partial modularization of components;
- Prefabrication of elements of the construction.

Modularization or modular design has been described as the key to prefabrication [1]. Modular design refers to construction using standardised units or standardised dimensions. Modular buildings do not have to be built using prefabrication techniques, but they are usually involved.

Frame construction is one route for introducing prefabricated elements into the construction process, and timber frame in particular is an approach which has continued to have a presence in the UK construction industry. Timber frame construction has a mixed history in the UK. In Scotland timber frame has become a well established technique for house construction and enjoys a majority position in the market. In England and Wales the situation is quite different with traditional masonry systems being used for the majority of housebuilding. There are pressures on the housebuilding market from tighter Thermal Regulations that may encourage further development of the timber frame market in preference to traditional systems. Some private housebuilders are beginning to increase their timber frame system production in the UK by opening new factories dedicated to this. A World in Action report in 1984 highlighting some problems in the timber-frame construction industry has left a legacy in England and Wales that is only recently being left behind. Timber frame systems for housing are generally prefabricated small panel wall systems, although some manufacturers are starting to market volumetric construction products.

Prefabrication is not just limited to the building fabric, but can also be applied to the plant and services within a development. The Building Services Research and Information Association (BSRIA) have recently completed a DETR study into the application of prefabrication to services [2]. This included comparison with traditional approaches and identification of some of the issues that determine whether the approach is successful.

The implementation of prefabrication in UK construction has been sporadic, and often dominated by the larger construction companies who have shown most interest in using prefabrication and standardisation techniques to improve productivity and move towards leaner construction. Often these applications have been focussed in the larger urban environments, where the economics of site time dominate.

3.2 Benefits of Prefabrication

Using prefabrication in a project allows the time spent working on site to be reduced. This means that the impact of the site on the local environment is for a shorter period of time. Site work is traditionally vulnerable to disruption from extremes of weather, by using prefabrication the site will be vulnerable for less time and so the risk of delay and requirements for protection will be reduced for a given project. Some major retail clients are actively targeting continual reduction in the site development time with an overall reduction of 50% in project time being believed to be a realistic goal, prefabrication is an active part of the process that will help to deliver these savings.

Fast track construction systems often use prefabrication components to rapidly erect a weather tight shell of the construction. This enables the internal fit out to be moved forward in the process and continue despite external weather conditions. Some of these systems use well established European systems, for example the thin joint masonry products that are now becoming utilised in the UK market.

Where prefabrication is being used in a project it is important to include it in the process as early as possible, and ideally at concept design stage [3]. Problems of lack of compatibility and resulting increased costs are common where prefabricated components are not considered until later in the process. Prefabrication requires that all involved in the process go through a learning curve to optimise the benefits of using the system. Changing the design of an ongoing project that uses prefabricated components introduces a range of problems for realignment as components are generally delivered to site to fit a specific set of dimensions. Working to greater precision with good supervision should reduce the amount of adjustment and realignment that is necessary. Construction IT co-ordination has potential to ensure that alignment and precision are maintained both on site and in the factory prefabrication activity.

Prefabrication can offer opportunities for dealing with problems from the declining workmanship standards and skilled labour shortages on site. In factory environments the quality of the finished product is much easier to assure than on site, all that remains is to ensure that the on-site assembly meets the required standards to allow the design to perform to requirements. Careful attention is needed with this however, as it has been a stumbling block in past application of prefabrication systems.

Careful quality control of manufacturing processes enables waste to be controlled and minimised through appropriate design and recycling opportunities. In addition the use of prefabricated components should cut the volume of site spoilage associated with current practices of over-ordering and poor site handling for the equivalent traditional processes.

The possible environmental consequences of using prefabrication and modularization are considered in Section 4.

3.3 Policy Agenda

The Egan Report "Rethinking Construction" [4] published in July 1998 by the Construction Task Force investigated the performance of the construction industry in the UK. The report found that UK construction needed to concentrate on becoming more efficient, improving the quality of its output and improving the satisfaction of construction clients. This suggested industry needed to:

- Drive down construction costs (annual target of 10% reduction in capital costs);
- Increase the quality of construction (annual target of 20% reduction in defects and accidents);
- Move towards sustainable construction with emphasis on prefabrication and off-site assembly;
- Become more innovative to streamline the construction process (annual targets of 10% increase in productivity and profitability, and a 20% increase in the predictability of project performance);
- Develop partnering between contractors and suppliers to move towards a dispute free industry.

The Egan Report led to a range of initiatives that have had a major impact on the construction industry, these include the Movement for Innovation (M4I) and the Construction Best Practice Programme. Prefabrication has been identified as a major way forward in delivering these required improvements.

One of the reasons for the specific highlighting of prefabrication as a route for meeting the Egan's targeted improvements is that it releases pressure from the current skills shortage present in UK construction. However, concern has been voiced that the very move to prefabrication will further reduce the skills base in UK construction. In 2001 Ian Davis, the Director General of the Federation of Master Builders made the following response [5]:

"Increased prefabrication is seen as one answer to problems that beset the industry, including the skills shortage, inconsistent quality and low margins. Whilst prefabrication has a role in improving the industry it must not be pursued at the expense of the skills shortage training needed for traditional forms of construction."

Prefabrication is much more than a trendy concept, it offers the possibility of remoulding construction as a manufacturing industry. It represents one of the positive ways forward for underpinning the major changes that have been identified as necessary for improving construction.

The DETR produced a Housing Green Paper "Quality and Choice: A Decent Home for All" in April 2000 [6] which identified prefabrication as a way forward in providing

affordable housing, and have considered ways in which more resources could be used in schemes that use prefabrication. The paper states that:

“We expect to see progressive take-up of the technique over the next few years, for both social and private house building, as the benefits are more clearly demonstrated.”

In September 2000 the Construction Minister Beverley Hughes launched a quality scheme for timber and brick construction which specifically looked at the issues of prefabrication. This scheme was developed in response to the recommendations of the Egan Report, it has been put together to address the following priorities:

- Eradicate bad practice in construction;
- Encourage greater use of prefabrication techniques resulting in construction efficiency and reduced costs;
- Re-train the industry’s workforce to tackle the decline of the traditional skills resource.

Other work for the DETR [7] has identified prefabrication and off-site assembly as one of the areas where opportunities exist for innovation and improvement in the construction process. However, it also illustrates the findings that the construction sector spends relatively little on R&D (0.6% of sales) when compared to other sectors such as the car industry (3.6% of sales) which is often considered as a model to which the construction industry should try to aspire.

3.4 Barriers to Application

The Government has recently sponsored a study to examine the potential barriers to use of prefabrication and some of the ways in which these may be overcome [8]. In particular the study was asked to look at how the potential barriers can be minimised by optimising the social, economic and environmental factors that surround the house construction process. These are the same generic factors that underlie sustainability within the construction industry.

The following issues have been identified from the Desk study as barriers to uptake:

1. General Image

As previously described, the image of prefabrication is coloured by the experience of past application, and in particular the results of the 1960s high rise housing systems. Many of these problems come from workmanship rather than design deficiencies. These experiences present a barrier to some parts of the construction industry accepting prefabrication as a viable method of building procurement. However, this is now being countered through one-off demonstration systems where close supervision of site activity should ensure that the end result is a product with workmanship quality equivalent to that of traditional systems. The quality of assembly is important in ensuring the long term success of prefabrication systems, the skills necessary for

successful implementation are central to whether the mistakes of the past are left behind. The test now for prefabrication is to move from the successful one off demonstration projects to mainstream developments, which for housing lie in both the private and social landlord markets.

For non-domestic buildings there is a wider acceptance of the use of some prefabrication in the process due to the demands of major clients who want to improve the efficiency and speed with which they procure their buildings

2. Perceived Performance

Much of the prefabricated housing that was built between 1946 and the mid 1970s has been viewed as having a shorter lifespan than that of equivalent traditional buildings. The perception that prefabrication offers a non-permanent solution is one of the potential barriers that exist for its wider acceptance as a mainstream procurement option.

In the non-domestic sector the importance of lifespan is mixed. Large out of town retail developments are designed to have a relatively limited lifespan over which the performance of the building can be maintained. The introduction of whole life costing as a tool for looking at the implications of different design strategies will be applied to building incorporating prefabricated systems so that the client can procure a building with known financial implications over its service life. This type of attention is particularly important for PFI procured buildings.

3. Customer Expectation

One particular barrier to adoption of prefabrication systems in housing is the perception that the public want traditional brick finished housing. Timber frame housing systems are usually finished with an outer cladding of brick, other innovative systems include those which have brick slips mechanically fixed to the outer surface of the wall in an attempt to mimic the traditional finish. The masonry industry are developing new factory prefabricated systems that can be delivered to site and which will allow a further route for delivering housing which maintains the traditional masonry appearance whilst being delivered through a prefabrication route. Housing Associations are beginning to procure multi-unit estates with prefabricated systems, feedback from occupants has been positive.

This is a domestic housing issue, there is a far wider acceptance by non-domestic sector clients for buildings to have innovative and non-traditional appearances.

4. Perceived Value

It has been suggested that resistance to prefabrication, particularly in the housing sector, is partly caused by the perception that property is an investment [9] and prefabrication is not necessarily seen to be a good investment based on historical experience. This needs to be considered carefully in the context of the economic aspects of sustainability.

As with perceived performance, the non-domestic client is much more likely to actively evaluate the through life performance of new buildings and have an

understanding of the investment value of their developments. As with housing the effect of prefabrication on the through life environmental value of non-domestic buildings needs further consideration.

5. Industry Culture

One factor that is restraining the use of some forms of prefabrication in housing applications is the availability of plant for handling the larger prefabricated systems on site. This is a problem specific to the house building sector as the use of appropriate plant is more widespread in the non-domestic market. In Europe the use of cranes on even modest housing developments is well established and part of site culture, in the UK lack of this provision makes the installation of panelling systems in housing developments more difficult. Some manufacturers provide cranes with their lorry delivery systems to enable the installation of the prefabricated components, however, where such systems require later adjustment there is a need for site based plant. Industry is addressing this to some extent by modifying existing plant (usually excavators) so that prefabricated components can be slung under digger arms for movement around site. A change in site culture and industry use of plant would enable better ability for developments to use panel prefabrication systems.

Experience of prefabrication used in even some of the more high profile schemes, for example the Greenwich Millennium Village Project has been mixed. The attitude of the construction industry has suggested that the industry is reluctant to try new methods and believes that off site manufacture will cost more than traditional methods of construction. Despite evidence to the contrary, this attitude still found in some parts of the industry is difficult to counter.

6. Product Awareness

The procurement of prefabricated components for a project is often a matter of designers being aware of the availability of a given system. Designers are unlikely to use a system for which they don't appreciate the benefits for the construction, or for which they don't understand how the system impacts on the design process.

Manufacturers are producing innovative prefabricated products, they consider that it is the designers that are conservative and reluctant to try out new systems [3].

The above barriers are often based on a perception of difficulties that have arisen from past experience, rather than from actual technical constraints. For systems correctly specified and used none of the above barriers should exist, the industry needs to be educated of the merits and benefits of using prefabrication.

It is noteworthy that some aspects of prefabrication used in construction have managed to avoid many of these problems and are well established as systems used in construction. One such example is that of precast beam and block flooring, the use of these systems has more than doubled in the last 5 years.

4. Sustainability Aspects of Prefabrication

At a European level prefabrication has been identified as having a role to play in making construction activity more sustainable. The PREPARE programme (Preventative Environmental Protection Approaches in Europe) [10] has a thematic group tasked with looking at Building, and has as one of its specific tasks to consider efficient technologies in prefabrication. They hope to:

- Develop prefabrication with optimal flexibility and functionality;
- Improve more efficient technologies (reduced materials input and costs);
- Increased quality of product.

The following sections consider the environmental economic and social aspects of sustainable construction.

4.1 Environmental Aspects

The Movement for Innovation has a working group under Rab Bennetts looking at the performance indicators required for measuring the sustainability of construction projects. They have identified the following six indicators [11] to be measured:

- Operational Energy Use
- Embodied Energy
- Transport Energy
- Waste
- Water
- Species Index per Hectare

These performance indicators are likely to be considered for inclusion as some of the factors to be used in assessing the prefabrication case studies later in this project.

The types of environmental benefit that can be anticipated from prefabrication will depend on the specific systems chosen. Undoubtedly systems could be used which have a worse environmental performance than typical traditional construction, but the potential exists for prefabrication systems to have better environmental performance.

One specific scheme being developed with EC funding has been quoted as having the following potential anticipated benefits [12]:

- 50% reduction in the amount of water used for construction of a typical house;
- 50% reduction in the use of quarried materials used in the construction;

- At least 50% reduction in the energy consumption.

Whether these performance improvements are achieved deserves scrutiny, but by implication prefabrication is being considered to show increased performance when compared to traditional construction in at least three of the Movement for Innovations performance indicators for sustainability.

Another important factor associated with prefabrication techniques is that of the reduction in waste associated with construction. Again this is one of the Movement for Innovations performance indicators.

The effect of a building on local ecology and species is going to be strongly influenced by design and landscaping which should be largely independent of whether the building is procured through traditional or prefabrication routes. However, one issue that could be important is that associated with damage caused by pollution during construction. Prefabricated buildings should have more control associated with factory based prefabrication, which should reduce the risk of some of this pollution to the local environment.

Transport may be the one M4I environmental performance factor where prefabrication could perform worse than traditional construction. In the case of volumetric construction in particular the transport of components to site necessitates the movement of some volumes of air which isn't as efficient as more traditional delivery. In addition the factories where components are made may mean significant journeys are necessary to service some locations in the UK.

Manufacturers of some of the prefabricated components are being proactive in considering the environmental impacts of their products by developing standards for materials procurement, recycling, pollution control and waste minimisation, for example Trent Concrete [13].

The environmental performance of prefabrication against the different M4I measures is illustrated in a qualitative way below in Table 1. Quantitative evaluation of this performance for different prefabrication options is needed to clarify the real benefits and drawbacks of using prefabrication and modular construction. The case studies to be developed later in this project will focus on this.

M4I Sustainability Indicator	Effect of Using Prefabrication
Operational Energy	Positive – Improvements in build quality should ensure consistent standards of insulation and service installation.
Embodied Energy	Positive – Reduced waste and increased recycling in off-site manufacture should reduce the embodied energy associate with the manufacture of a given part.
Transport Energy	Negative – Movement of prefabricated components will necessitate the transport of some additional volumes of air (particularly for volumetric solutions)
Waste	Positive – Manufacture of components in a factory environment should reduce much of the waste currently associated with site activity.
Water	Positive – Manufacture of components that require water in their manufacture in a factory environment should allow more control, and potential for water recycling than would be found on site.
Species per hectare	Positive – Reduction of pollution on site by undertaking manufacture in a controlled environment should limit the impact on existing species on site. However, the design and landscaping of the proposed development is likely to be very important and unaffected by the choice of prefabrication or not.

Table 1. Qualitative Performance of Prefabrication against the M4I Environmental Performance Indicators

4.2 Economic Aspects

The EC have funded a Sustainable Construction project called Futurehome which seeks to help EU States meet the social need of affordable housing [14]. The project is being co-ordinated by Dr Robert Wing of Imperial College. The Futurehome project seeks to build up a pool of data on building prefabricated low to medium rise housing, and is

hoped to provide the basis for developing sustainable and adaptable building concepts using prefabricated technology. The project aims to deliver:

- A 30% reduction in construction costs;
- A 35% reduction in construction time;
- A 60% reduction on defects on completion.

These type of improvements if confirmed would show that prefabrication has a major role to play in meeting the Egan targets and that part of the economic aspects of sustainability can be addressed through prefabrication.

One UK housebuilder, Westbury Homes [15], has been looking at prefabricated systems that could enable the erection of the structural elements of new homes in less than 24 hours. Such performance is a considerable advance on that which could be achieved with traditional methods and illustrates the potential productivity implications for developers using prefabrication technology.

4.3 Social Aspects

The challenge for prefabrication in the housing sector is to leave behind the association of some types of system with poor quality housing and even social exclusion in some extreme cases. This is at the root of whether prefabrication can be successful or not in the housing sector, and both designers and manufacturers need to come to terms with this. If prefabrication becomes linked again with these problems, then there will be a risk of it being viewed as a socially unacceptable system which, regardless of other technical merits and environmental benefits, will be viewed as a failure.

The case for non-domestic buildings is rather different. For years some retail developments, fast food restaurants and hotels have been procuring buildings through a prefabrication route. Little, if any, social problem is associated with these being procured through prefabrication, and in many cases there is little public awareness that they are such.

5. Potential Future Uses of Prefabrication

Currently prefabrication is used to some degree in all aspects of construction the future applications are likely to remain the same, however, the extent of application is limited by a range of factors as detailed in section 3.3. One of the more important challenges for the future of prefabrication is to overcome these barriers and in particular ensure that the mistakes of the past are not repeated in the current prefabrication activity. Failure to do this will result in prefabrication not meeting its future potential in the UK.

Prefabrication has the capacity to drive down costs and improve the productivity of the construction industry, claims for level of improvement that can be achieved need to be scrutinised and evidence is required to support them. Other selling points for prefabrication are the improvements in quality that can be achieved through factory controlled manufacture of components and the avoidance of problems with site skills shortages, by off-site manufacture. All of these issues need to be understood and properly demonstrated for the more conservative parts of the industry to begin to respond to the benefits. This should lead fuller uptake of systems.

The potential environmental benefits of prefabrication are numerous, however, real assessments are required of different prefabrication applications to show whether these benefits are marginal or more significant when compared to traditional construction solutions. This information will allow the context of prefabrication within the move to sustainable construction to be established. The case studies to be developed later in this project should give some useful information to demonstrate the level of environmental benefits that can be achieved. Environmental legislative pressures on construction activity are likely to continue to grow in the future, if environmental benefits can be demonstrated for some systems then the systems should flourish in the future.

The future applications of prefabrication in UK construction will be determined by the economic and environmental benefits that can be demonstrated for particular applications. In order to ensure that these are successful the performance of the systems need to be established over their whole life of the structure. Without market acceptance of the end product, prefabrication will not flourish, it is important therefore to ensure that the aesthetics of the system meet market demand, this is a design rather than technological challenge.

6. Conclusions

Prefabrication is a well established procurement option in the UK. There are, however, a range of barriers to its full potential use which stem from past experience of prefabrication which have left it labelled as a poor quality product with associated social stigma. Prefabrication within the housing market is most affected by this perception, yet offers considerable opportunity for those willing to use it properly.

The benefits of using prefabrication include:

- Higher quality products for clients;
- Improved productivity and profitability for contractors;
- Environmental benefits associated with its use.

There are numerous figures quoted by industry sources of the potential savings that could be made with systems, however, little independent assessment of actual performance has been made. Such independent confirmation of real performance characteristics is needed in order to overcome the perception of parts of the industry that prefabrication is a poor quality substitute for traditional construction approaches. The next stage of this project will focus on developing this level of information from particular case studies of prefabricated construction and comparable traditional construction.

Prefabrication has the capability to make a difference within the UK construction industry in economic, social and environmental terms. It is important that how much of a potential difference it can make is established so that appropriate development can be implemented.

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Appendix A – Project summary

The objectives of this project are to inform and encourage the appropriate adoption of prefabrication and modular construction techniques by providing comparative data on a range of key sustainability indicators.

This will be achieved by working with developers and housing procurers to identify and study six pairs of social / private housing and commercial developments. Key indicators of sustainability will be identified early in the project but these will include: process energy/CO₂; operational energy /CO₂; transport related impacts including CO₂; resource use including materials; water consumption; waste minimisation and management; social acceptability; flexibility in use; capital and life cycle costs; ease of construction; profitability.

The results of this work will be disseminated to developers and financiers of housing and commercial buildings through a carefully targeted publication and web site information.