FutureHome – A PROTOTYPE FOR FACTORY HOUSING

by

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ABSTRACT: The manufactured housing project ***FutureHome***, which received major funding from the European Commission, has developed the engineering know-how to create affordable, high quality, cost effective manufactured housing, with a customer focus that takes account of diversity of styles, designs, materials and locations. The provision of housing to an acceptable standard is becoming an increasingly serious problem worldwide, and the widening gap between supply and demand points to manufactured solutions as the most viable way forward.

FutureHome has developed systems for product and process analysis suited to manufactured and prefabricated construction solutions, and these have led to design prototypes. To mark the end of the research phase of the project, one design has been built to full scale as a demonstrator. The research has led to leaner design and construction processes that focus on value for money, improved productivity, maintainability and sustainability. It has also focused on basic engineering requirements such as fast connectors, and automation solutions for materials handling and assembly. Further aspects of the research programme have considered how the product can be adapted to areas of high seismic risk, and has developed software solutions for design and management from a virtual-reality customer interface to cyber-agents for logistics.

FutureHome is expected to have benefits through savings in construction costs and time, significant reductions in defects on completion, and will enable industry to be more competitive overall. Other benefits include improving the quality of life, social fabric and health of the European economy through a more efficient and effective construction process.

Keywords: housing; manufacture; construction; automation; process

1. INTRODUCTION

FutureHome is a European R&D project bringing together fifteen partners from six European countries, and forms part of a global project under the Intelligent Manufacturing Systems (IMS) programme. This project has explored the potential to apply advanced manufacturing technology to housing design and production, aiming for significant construction cost and time savings, and major reductions in defects on completion. The studies have shown that high quality can be delivered at a fraction of the cost of the traditional construction methods that currently dominate the market. A strongly IT oriented approach is seen to be fundamental, with state of the art simulation tools for support of the design and construction processes and effective involvement of the customer.

The project is industry-driven and draws on the substantial expertise and resources of some of Europe's major manufacturers and niche contractors – all with a reputation for developing and applying innovative solutions.

The European Commission supports the project under its *Brite*-Euram programme, enabling leading European research institutes and universities in this field to work alongside the industrial partners; the European consortium has a formal collaboration agreement with IMS project IF7, "The Intelligent Field Factory", involving a large Japanese research consortium. The Japanese

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project is primarily concerned with larger, particularly taller, structures, but in other respects its objectives parallel those of ***FutureHome***. That consortium includes three major construction companies in alliance with universities and research institutes *[Ref. 1]*.

2. HOUSEBUILDING AND EUROPE'S ECONOMY

At the start of the 21st Century, much of manufacturing industry is exploiting the efficiencies of mass-customisation, with design integrated to computer-controlled production. Customers enjoy affordable high-tech goods and, particularly in the fields of communications and entertainment, see improvements to their quality of life and work. The housebuilding industry, however, is slow to adopt the benefits of our post-industrial digital age, opting for the traditional craft approach with its rather variable output quality.

Attempts during the 20th Century have failed to provide a factory approach to housing construction, and today's most advanced offerings, represented by pre-fabricated modular systems are struggling to gain their market. Factory-produced panel constructed housing is gaining popularity in the Netherlands and Germany (*Fertighaus*), where this approach has become a substantial industry sector *[Ref. 2]*. The main advantage is that many of the construction processes are brought indoors, and benefits then arise from reduced weather impact on scheduling, and the relatively easy availability of machines and services in a well-structured factory environment.

Extension of this principle into 3 dimensions is seen in modular prefabricated housing. Here entire room sized units can be completely fitted out within the factory and delivered to site for assembly. A demonstration project of this type has been recently completed in London (Murray Grove), where it was the client, Peabody, the UK's largest housing trust, that drove the initiative to use modular methods; the general success convinces it to use the same concept on further projects.
Such projects, however, represent only a minute proportion of the construction industry, the largest industrial sector in Europe's economy; with an output of 780 million Euro it exceeds Japan's construction industry by 10%, and that of the US by 30%. It is also Europe's largest employer, providing jobs for 11 million workers, and with each construction job generating another two in related sectors some 21% of Europe's workforce therefore depends directly or indirectly on construction.

In this time of sociological, demographic, and rapid technical change, the industry is adapting to many new challenges, including:

- *Creation of multi-functional buildings capable of adapting to the changing nature of work and leisure.*
- *Provision of housing for Europe's ageing population, offering comfortable and autonomous lifestyles.*
- *Provision of quality urban environments.*
- *Reduction of energy usage, buildings currently being responsible for more than 40% of total consumption.*
- *Reduction of waste; future building products need to be re-usable and recyclable.*

The above factors, together with client demands for both quality and quantity in the housing sector indicate that factory methods will be essential in the future if the industry is to handle future demand and avoid loss of this market to foreign competition. The greatest challenge for the industry is to leave traditional methods behind, and evolve solutions based on a fully manufactured house rather than simply introduce factory-prefabricated parts into current processes. The perceived solution is mass-customisation rather than custom-build, together with an IT-based approach to design and construction.

3. THE *FutureHome* CONCEPT

FutureHome's priority has been to evolve a design system that takes account of the diversity of styles, designs and material composition, and especially the preferences of owners and occupiers, that is, customers who are as diverse as Europe itself. All share the same basic requirement of a home that is affordable, decent, modern in its facilities and capable of adapting to changing needs. The general maintainability of the products of

FutureHome, employing materials and components that can be reused, is a key objective.

New approaches to design and production are needed, for assembly in a controlled, factory environment by a higher skilled labour force, using materials more efficiently, and involving low energy use in operation. These, in any case, are essential elements in Europe's path towards sustainable development.

Production has to be divided between fixed plants for component manufacture, and field factories for assembly of larger units local to the construction sites. The field factories reduce the overall transportation resources required, and importantly will bring employment to the area undergoing regeneration. It is not, however, an easy change for the traditional housebuilding industry, and it is possible that the initiative for setting up the manufacturing facilities will come from another industry sector, as has happened in Japan.

The current panel-based pre-fabricated housing systems use production processes based on labour rather than machines. They address part of the problem, as site-based employment becomes less attractive to prospective construction workers and consumers demand more consistent quality. Systems based on steel, timber and concrete structural components have been developed, but only steel and concrete would be suitable for the full range of apartment types and heights required, and the economical transport radius for concrete systems is limited. Thus the core components in a new European housing industry would need to be fabricated from steel *[Ref. 3]*.

Small-scale suppliers of pre-fabricated buildings based on light steel frames exist in most European countries. The challenge is to create a more efficient integrated production system, taking advantage of these firms' knowledge of local requirements as well as drawing on the expertise in other industrial sectors with long experience in combining customisation with mass manufacturing technique. Customisation is the key to the success of this approach; current housebuilding supply chains are not robust enough to tolerate the variabilities in customer demands because capacity is not engineered into the system.

The IMS link with Japan has been valuable in understanding the market requirements, as in that country mass-produced, customised homes have secured 7% of the new housing market, and with excellent customer response

Development of the new housing systems and associated manufacturing plant proposed in ***FutureHome's*** outputs will contribute to the regeneration of urban areas, create new skills, and establish integration of the technological, social, economic and business aspects to support the future provision of housing in Europe.

4. *FutureHome's* ACHEIVEMENTS

The engineering R&D within the project covered three linked areas:

- **Building System studies**.
- **Automation studies**
- **IT studies**

Examples of ***FutureHome*** innovations and developments from each area are given below; it is hardly necessary to state, however, that even this large project barely scratches the surface of the major gains obtainable from a full factory-based solution.

4.1 The *FutureHome* building system

The ***FutureHome*** building system derives from a Kit-of-Parts approach, wherein standardisation plays a significant role in achieving economies from the many variations allowed in the parts set. The choice of light steel framing for the pre-fabrication base comes from transport logistics and the requirement to use automation tools both in the factory and on site. This demands assured dimensional precision and avoidance of problems such as warpage and shrinking.

Kit-of-Parts is a specific implementation of prefabrication; the distinction being that such structures follow an assembly, disassembly, parts replacement, re-assembly sequence as required during their life-cycle. Normal prefabricated structures, however, can only be taken apart with loss of functionality, either due to unavoidable damage or irreversible jointing.

The general modular concept, I-KOP, or Integrated Kit of Parts, centralises the provision of services in standardised core modules, leaving considerable design freedom for the outer (less serviced) modules and panels *(Figure 1)*.

4.2 Production optimisation for prefabricated buildings

The balance between site and factory processes, and the optimum level of prefabrication for housing designs are analysed using software tools such as DSM (Dependency Structure Analysis), a systems analysis tool for the investigation of interactions and interdependencies between elements in a complex system – modules and sub-systems in this case. Used on the architecture of the product, DSM determines possible integrative components, in other words, it seeks potential for employing larger factory pre-fabricated modules. Used on the assembly process DSM creates optimised task sequences that can be fed into planning tools to determine the critical path for the assembly process.

Additionally, IDEF0 process analysis methods have been used to produce optimised workflow procedures for the purpose of providing a model of the total process for design and manufacture of ***FutureHome*** products. The aim has been to create a single, integrated model of the process from which views of the various phases can be mapped in detail. Information has been sought from the project partners and from outside the project to develop this blueprint for total process control.

The use of the international standard, IDEF0, to portray the logic of the process, its activities, information flows, controls (i.e. constraints) and mechanisms (i.e. personnel and tools) within the model brings together in one place the core information needed to organise and manage the design and manufacture process. *Figure 2* illustrates the top-level view of the process, which is decomposed into lower levels of detail that equate to specific work flows.

Using *BPWin* software, a detailed model has been created, with activity, cost and time data incorporated. The model has been used to export these data to an ODBC-compliant database (*Microsoft Access*), located on a password protected web site: the term Process Control Interchange has been given to this development. Authorised users can interact with the model's database to import data for cost estimating and time scheduling. Other data can be exported to assist in defining work flow and decision control procedures.

One of the benefits of this modelling approach is that a change in any one element is reflected automatically in the rest of the model, thus preserving data integrity. Different arrangements within the process can be tested and optimised.

The model combines an earlier model for the design of a structure at full size, with those for off-site manufacture and on-site production of the components and assemblies. This holistic view of the process provides the basis for the development of ICT tools for automating work flow. Output from the model can be interchanged with many applications, allowing value to be added to the basic process model.

4.3 Connectors for automated assembly

Complementing the Kit-of-Parts, connectors have been developed for ***FutureHome*** modules, covering structural, assembly, and services requirements. These are seen as the essential means of enabling the use of intelligent machines for assembly processes, and they make use of *Design for Assembly* and *Smart* concepts *[Ref. 4]*.

For site assembly of prefabricated modules using conventional construction site plant equipment, conical paired assembly connectors allow auto-centering of modules. A computer-controlled 1/5 scale crane was built for evaluation of this approach to site assembly of large modules *[Ref. 5]*. Snap-fit structural connectors for modules and panels have also been developed, using plastic compression spring fastenings.

A universal services connector provides a highly standardised factory fitted system, where traditionally a variety of tradesmen are involved on site. The object here was to develop a connection system that not only reduces pure on-site assembly time by use of a fast mechanical connection, but also brings a substantial reduction of the total assembly time by off-site integration of trades (*Figure 3).* It will thus be possible to increase added value in the factory and deliver components of large manufacturing depth and a high degree of prefabrication to the construction site. In addition to the cost advantages, quality improvement is assured.

4.4 Cyber-agent technologies

Cyber-agents as decision-making aids have many potential applications in both on and off-site construction processes. The project has investigated some specific examples, addressing agent communications issues extensively, covering agent-agent as well as agent-human operator interactions. The lack of international standards, security, and network bandwidth are seen as the main problem areas in their implementation.

A materials delivery agent was developed as a demonstration of this technology. Using electronic tagging devices attached to individual components, the delivery cyber-agent tracks parts, reconciles items with orders, and interfaces with the construction database. Information is stored in attached 'e-tags', which for the type selected have up to 64Kb memory.

4.5 Visualisation developments

Visualisation methods provide support on several levels in this project. VR is employed to complement the Kit-of-Parts, providing a common virtual environment to be shared by clients, architects, engineers, constructors, maintenance providers, etc. Thus clients can be led through the virtual design of their house, which is created on-line using prefabricated components from the Kit-of-Parts.

In addition to the house model, a simulation of the construction process of the house is provided, allowing examination of cost, quality and time parameters *[Ref. 6]*.

The design environment within which the user can create a design from its constituent prefabricated components *(Figure 4)*. A 3D window (top left) lists the components available from the current library. The user can select a component and view it in 3D; they can then choose to add the component to the design, using collision detection and constraint based modelling techniques to ease the interaction process. As the design process proceeds, a window within the environment keeps the user updated with the total component cost of the design.

The user then moves to the construction environment for an animated simulation of the construction process *(Figure 5);* this includes a tower crane and other virtual site equipment.

4.6 Performance and economics

Space limitations preclude adequate presentation of many of the innovative contributions from this large partnership, especially those relating to the use of IT. The research has included developments required to ensure a satisfactory whole-life performance for the products, and to deliver good value for money. Building physics issues have included structural analysis, thermal characteristics and ventilation issues, acoustics, seismic performance, regulatory, sustainability and ecological requirements – especially those regarding material choice and reuse. These, together with architectural, aesthetic, and environmental considerations are clearly essential to any design for future housing.

As the main phase of this project ends, the partnership believes that the ***FutureHome*** project has significantly progressed the arrival in Europe of a fully factory-based approach to housing that exploits the benefits of today's digital technologies. The use of visualisation and mass-customisation concepts will, we trust, avoid the greatest perceived danger, that of factory housing being associated with styles that are bland and incapable of expressing custom or culture.

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FIGURES

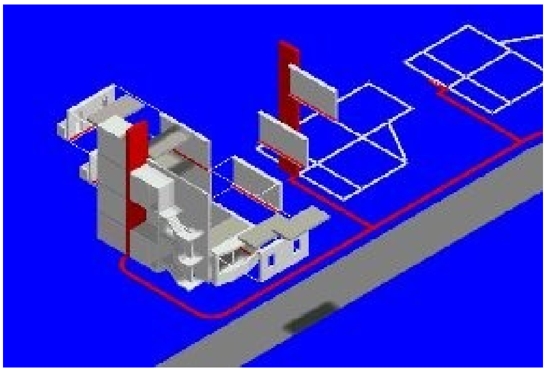

Figure 1. I-KOP Building system

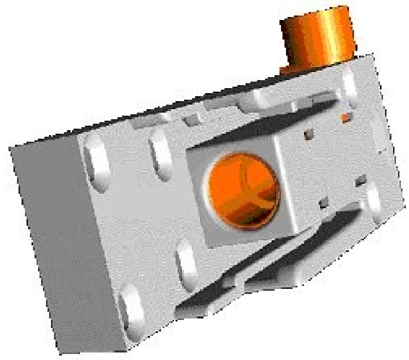

Figure 3. Services connector prototype

Figure 2.
Top level IDEF0 process diagram

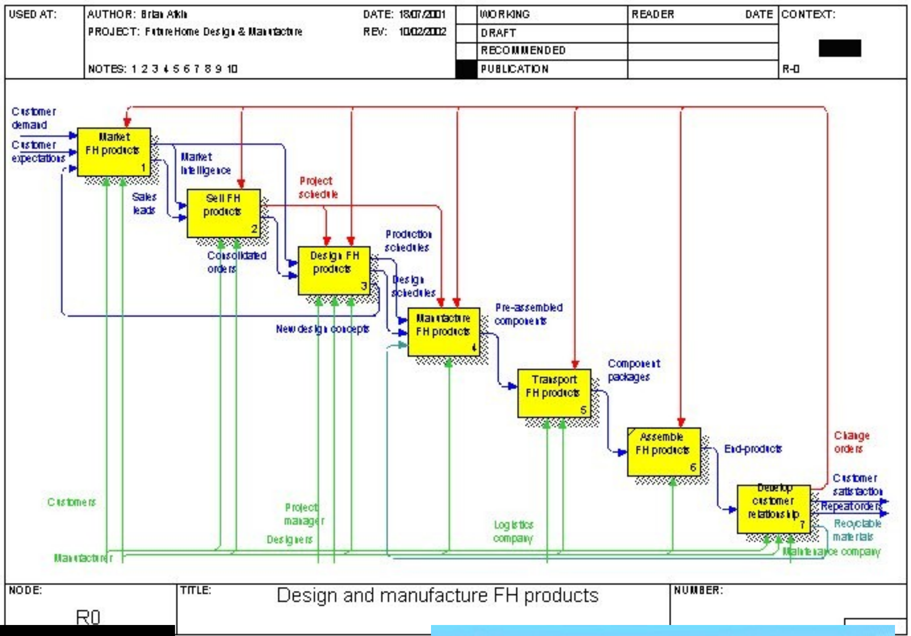

Figure 4. Virtual design environment

Figure 5. Virtual construction site