DEVELOPMENT OF A PROCESS DOCUMENTATION SYSTEM FOR THE HOUSE-BUILDING INDUSTRY

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The UK housing industry has often been criticised for the quality of its products. There is growing interest in the industrialisation of house building methods. Much of the focus of attention has been on the use of manufactured structural components, which addresses the inherent problems of reliance on ‘wet trades’. However, there is a need also to improve the quality of the assembly and ‘fitting’ processes on site. The house building process has tended to develop more through custom and practice rather than formal analysis of methods. There is a lack of standards, and of mechanisms for process review or sharing knowledge and good practice. The result is significant process variability on site. Process documentation is a rigorous description of a process, procedure or policy to facilitate training, development of consistency of operations, and analysis and improvement of current standards. The paper describes work on the development of a process engineering information system that has already been partially implemented by a major house builder. Process sheets have been designed for effective communication of quality-care points, and the system supports feedback from site staff on operation standards and maintains an audit trail of changes.

Keywords: house building, information management, process improvement, quality.

INTRODUCTION

The UK housing industry has been criticised for poor build quality (Ball 1996), slow pace of innovation (Ball 1998), and for the excessive standardisation of products (Barlow 1999, Roy and Cochrane 1999). It has been slow to adopt new build methods compared to its counterparts in many other countries (Egan 1998). The only significant form of pre-fabricated houses currently is of timber-frame construction, mainly found in Scotland (Mackay 1996). A much greater degree of industrialisation, using a range of materials and build processes, can be seen in Japan (Bottom *et al.* 1994, Gann 1996), North America (Rhyn 1995, Lawson *et al.* 1999) and in some European countries (Cooke and Walker 1994, Gann 1999).

Industrialisation in house building is usually associated with the use of factory-built structural components. Much less attention has been paid to the assembly and ‘fitting’ processes on site, which exhibit the characteristics of a craft-based industry with significant process variability due to differences in skills and experiences of the workforce. The problem has been exacerbated by the industry’s reliance on self-employed craftsmen, which has been a factor in inhibiting innovation (Ball 1996, Clarke and Wall 1996). An important feature of industrialisation is the existence of well-defined processes that the workforce can adopt, and which form the basis for efforts at improving efficiency and quality. The paper presents work on a process documentation system to help standardise the build method, as part of a wider project

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that is being carried out with a leading builder to study the changes in working practices needed for the sector to develop into a customer-focused industry.

THE UK HOUSE-BUILDING INDUSTRY

The housing industry in the UK is dominated by speculative builders operating in the mass market for private, single-family dwellings, for whom the dynamics of land- and house-price inflation and speculative management of the land bank have traditionally been the main business drivers (Barlow 1993, Bramley *et al.* 1995). Innovation in building processes, and design and marketing of products has largely been of secondary importance (Barlow 1999). Speculative builders currently offer a relatively small range of products with customers given a limited choice of finishes, mainly in kitchens and bathrooms, if the order is placed in time within the build schedule.

The housing market in the UK has historically been highly volatile, and many reasons have been put forward to explain its boom-and-bust, cyclical nature (e.g. Stern 1992, Maclennan 1994). To reduce exposure during the lean periods and provide flexibility during market upturns, the industry has for many years tended to contract out the site work, often to self-employed craftsmen (Ball *et al.* 1988, Gann and Senker 1998). Competition between contractors was expected to act as an incentive for innovation and help ensure that the industry skill-base was maintained, but this has failed to materialise (Ball 1996, 1999). The house builders have been reluctant to make long-term investment in the work force that may also be working for its competitors, and there has been a decline in training schemes within the construction industry as a whole (Mackenzie *et al.* 2000). The result has been a serious skill shortage, an industry characterised by adversarial relationships in its supply chain and a low skill base (Ball 1996). Many workers within the trade gain skills from experience, rather than formal training in processes, and have little motivation to learn new methods.

An industry survey, carried out in 1997, found 45% of buyers of newly built homes dissatisfied with the quality of the products and services provided by vendors (NHBC 1997). Some quality-related problems are difficult to eliminate with the masonry construction method currently prevalent in England and Wales, which is heavily reliant on ‘wet trades’, but not all can be attributed to that. The use of sub-contract labour makes quality control problematic (Ball 1996), but certainly not impossible; there are many examples of companies in other sectors that contract out all work under licence. The craft-based approach to construction, however, makes process control difficult (Roy and Gaze 1999), and the shortage of well-trained workforce has exacerbated the situation. Many problems also arise due to a culture that is tolerant of failures, with an industry focused on completing tasks as quickly as possible, dominated by adversarial relationships and placing insufficient emphasis on quality (Ball 1996, Egan 1998). In the house-building industry, there is also a lack of any process documentation and even standards. This does not encourage process review and, even when innovations do occur, the dissemination of new knowledge is slow due to the lack of formal mechanisms for sharing good practice. The geographical spread of a builder’s operations and the strong regional structure commonly found in the industry (Bramley *et al.* 1995) also make it difficult to develop a corporate culture and identity. Such characteristics commonly contribute to process variability, both between and within sites, and in terms of quality and efficiency.

BUILD QUALITY AND PROCESS DOCUMENTATION

In contrast to the craft-based housing production in the UK, many countries in Europe and elsewhere have benefited from the use of innovative construction processes to produce better quality and greater variety of houses (Gann 1999, Barlow 1999); greater process efficiency has, in some cases, also resulted in lower costs – a study of social housing found average building costs to be 25% higher in the UK, in spite of lower wages, than in the Netherlands (Clarke and Wall 1996). There have been calls for the UK industry to adopt a similar approach and move from the craft production of a limited range of products to mass customisation of housing based on industrialised building methods (e.g. Barlow 1999). The initial emphasis has been on the build technology platform – the use of manufactured structural components to remove the inherent quality problems of ‘wet’ processes. As part of the wider research project with the Partner Company, a new structural panel system is currently being introduced in its operations. The storey-high panels are up to a maximum of 12m in length, and consist of two sheets of facing boards with a core of timber frame and injected phenolic foam (Gaze 1999). It combines the structural properties of timber-frame construction, the high degree of pre-fabrication inherent in a panel system for efficient assembly, and the excellent fire-resistance and insulation properties of phenolic foam.

If the full benefits of industrialisation are to be achieved, the rest of the build process will also need to be re-engineered for quality and efficiency. The dimensional integrity of the structural envelope provides the necessary framework for simplifying the assembly of ‘infill’ components and efficient customisation of the interior of the house (Roy and Cochrane 1999), but the whole process will need to be critically examined for opportunities for improvements. In the early phases of industrialisation, product engineering will play a key role in changing the ‘fitting’ process into one of assembly of engineered components. However, technology alone will not be sufficient; working practices that contribute to poor quality and inefficiency will also need to change. A clear definition and standardisation of the build process based on analysis of what constitutes good practice, and training of the workforce for its consistent application are important in developing the necessary culture.

Process documentation is commonly used in manufacturing industry. At its simplest level, it is no more than a list of operations to be carried out on a part or product (the process route), and is merely a source of information for the shop floor. In more sophisticated applications, however, it is a rigorous description of a process, procedure or policy to facilitate training, development of consistency of operations, and analysis and improvement of current standards. The work described here towards the development of a Build Process Documentation System (BPDS) has been informed by similar concepts recently developed and implemented in the motor industry (Roy and Allchurch 1997). Its objective has been to develop an information system for the creation, maintenance and distribution of process documents that will help with the review and standardisation of the house-building process, improve communication, encourage feedback and teamwork, and deal effectively with information on product variants in support of mass customisation.

PROCESS DOCUMENTS

The format of the process document sheets was designed based on experiences of the motor industry (Roy and Allchurch 1997, Allchurch 1998) and through extensive consultation with groups of site managers of the Partner Company. Manually developed sheets were piloted in one operating region for the 'finishing' stages of the build process (concentrating only on the generic features, and not issues that may arise from product variants). The resulting drive towards standardisation became a catalyst for examination by the site managers of working practices; the emphasis was on identifying quality care points, and structuring of the work for clear accountability.

The main considerations in its design were – simplicity of instructions, with the target user group in mind (site staff and workforce); avoid overlong textual description, concentrating on those aspects of the work that are critical for quality, efficiency and a safe operating environment; instead, make each sheet informative with appropriate use of illustrations; consistency of format across all regions, sites and operations to develop a sense of common purpose. It should also aim to collate information that currently may be dispersed in a multitude of documents, which often leads to confusion and mistakes.

Each sheet in BPDS describes a significant and self-contained operation of the overall build process, together with information on the materials/ parts and their quantities needed to carry it out. Careful consideration should be given as to what constitutes an operation in this context. An individual or team must have clear accountability for the work content of each sheet; the work should be a part of the overall process that can be completed to a measurable quality standard (Allchurch 1998). The textual description (work elements) is supplemented by an illustration, which is usually a photograph and may also include a CAD drawing or an artist's sketch; the system also provides for a video link to facilitate training, although this is yet to be implemented.

Almost half the sheet is devoted to the illustration, and considerable effort went into the development of high quality photographs/ drawings for the process sheets currently in use within the Partner Company. The sheet has an area set aside to communicate quality issues to which the workforce needs to pay special attention. Health and safety information is highlighted through the use of standard icons. The document identifies the range of products (or the plot) to which it applies, and also contains information related to version control – the process engineer responsible for the change notification, date it is issued, and reason for change. Figure 1 shows a schematic view of the data structure.

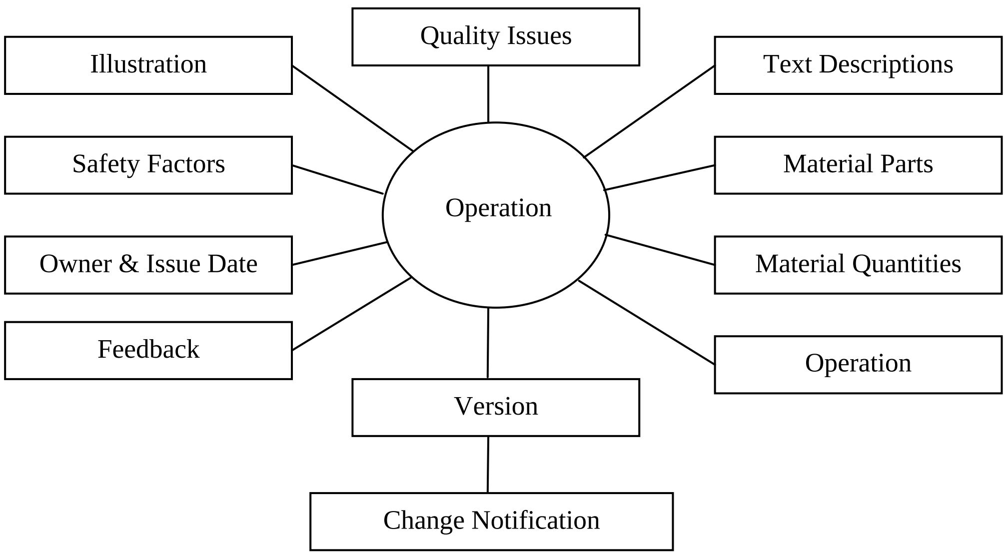

Figure 1: Schematic View of the Data Structure

VERSION CONTROL

Version control is an important feature of a process documentation system. At any point in time, a number of versions of a process/ operation may exist to reflect product variations, or new design or process improvements that are being introduced. With mass customisation, controlled introduction of product variety will take on added significance. In BPDS, creation and modification of the operation standards are carried out through a change control mechanism. This restricts who can make changes to the process, and allows an audit trail to be maintained. A process engineer opens a ‘change record’ to which can be added any number of existing and/or entirely new operations. The engineer then creates a new standards document for each operation in the list. Where a pre-existing operation is being changed, a new version is created, leaving the original unaltered. Once a new process has been defined, the engineer closes the ‘change record’, and the associated operations are set to an ‘Issued’ status. Any further modifications will require a new ‘change record’ to be created. If a new version of a current process is created, older versions are not immediately made obsolete (or archived), but set to a ‘Superseded’ status since they may remain in use for some time in some or all sites.

PRODUCT DEFINITION AND APPLICABILITY

Product specification data (in, for example, MRP II systems) is traditionally structured in the form of an engineering Bill of Materials (BOM), with process data directly associated with the BOM in the form of process routes. Such a data structure is inappropriate for definition of assembly processes in the case of large/complex products. In house building, process route is clearly not an issue, but variations in work content may exist between different products and their derivatives due to differences in footprint/ architectural styles, local planning regulations, customer-selected options, or even due to characteristics of the particular plot on which it is to be located. Some operations may be common to all products, while others may apply or vary due to one or more of these factors. It is necessary to have a succinct mechanism for defining the applicability of groups of operations to individual houses in order to manage and distribute the large volume of data in an efficient manner.

The characteristics of each product are defined in BPDS using ‘Modules’ and ‘Module Options’. A Module is a classification category for a key aspect of the house design. Examples might be Foundation type, Stair configuration, Cladding. Some modules (e.g. conservatories) may be applicable only to certain house types. A module option is a specific selection made against a module for a particular product design, e.g. ‘Half Winder’ for the ‘Stair Configuration’ and ‘Stone effect’ for Cladding. The process engineer can associate any number of operation standard sheets with a module option.

A house (on a specific plot) is built to the design of one of the builder’s standard portfolio of house types but, as indicated earlier, will often vary slightly from it due to local planning regulations, its particular position on the site, customer preferences, etc. BPDS uses a hierarchical tree structure to capture such variations. The root node represents all products, level one nodes in the tree represent the basic designs, whilst lower level nodes represent local variations. The leaf node can represent a specific house/ plot. Any modules and options assigned to a node are automatically inherited by all its direct descendents. The inheritance mechanism can be superseded at a node by deselecting the current option and choosing a different one. If the leaf node is for a specific plot, there will come a time when the build design will need to be committed and no further changes allowed. When a user with the appropriate authority commits the design, the system removes the node from the inheritance mechanism. A planned system enhancement will allow the commitment process to be carried out in stages, a module at a time, which will reflect better the customisation process. With this two-stage product definition, assignment of modules/options to product nodes and operation standard sheets to module options, the sheets can be collated flexibly for different groups of products. Figure 2 shows a schematic view of this arrangement. The system is able to locate the sheets applicable to the construction of a particular house type or design and to individual products. All the relevant sheets can be distributed as a work instruction pack, together with other essential documents (e.g. elevation drawings), when work is due to commence on a plot. The importance of this will be even greater as product variety increases; even with the current limited number of product options that are offered, there is anecdotal evidence of mistakes occurring, e.g. of building to the wrong specification or the wrong part being ordered.

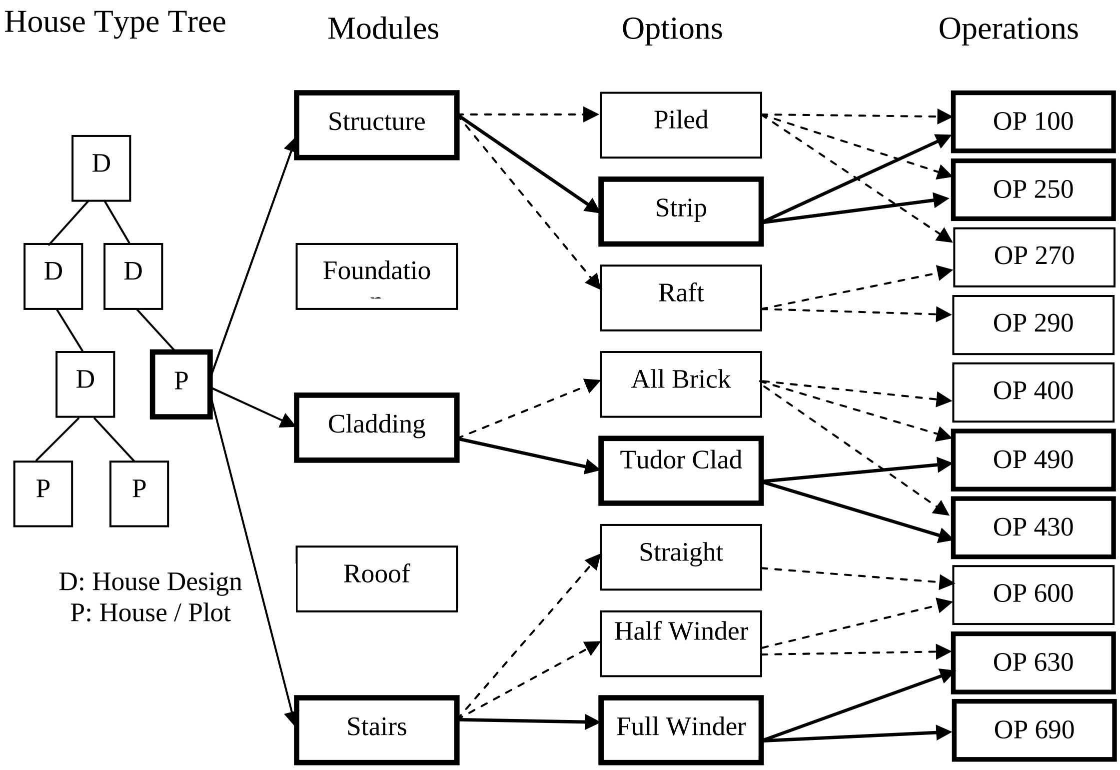

Figure 2: Schematic View of the Applicability Mechanism

Although this structure provides a reasonably good mechanism, inheritance trees have limitations in expressing complex sets of applicability relationships in a succinct manner, e.g. some operations in the build process may apply to all 5-bedroom houses, some only to L-shaped kitchens, while others to 5-bedroom L-shaped kitchens. Enhancements to the current structure are being investigated. One possibility is to use the names of the nodes in the tree structure to express relationships that traverses the product tree structure (e.g. operations apply to 'all 5-bedroom L-shaped kitchens').

COMMUNICATION AND TEAMWORK

Product quality and process efficiency depend on effective design for production/ assembly (Boothroyd and Dewhurst 1992, Hunt *et al.* 1993), and considerable progress has been made in much of manufacturing industry to develop teamwork between historically disparate disciplines to achieve this (Syan and Menon 1994), with the process engineer acting as the interface between design and production personnel. The concept of design for construction is also not new (e.g. Fox 1988), but its application in the house-building industry has been limited. An examination of the core competencies of speculative builders shows that traditionally they have been in land acquisition, sales/ marketing, and cost control and project management of the site-development work. Many builders have even contracted out much of the work on product design/ engineering which, in any case, has been viewed primarily in terms of functionality (often legislation driven), aesthetics and structural properties. Product and process knowledge are dispersed between architects, suppliers of key component systems, and sub-contractors and builder's own staff on site.

BPDS provides the infrastructure for sharing information and a formal framework for process review. The system also enables the creation of 'mark-up' layers, which can be used by the engineer responsible for creating the document to highlight on the illustration any special features of the process (for example, related to quality), or by its recipients to provide feedback on the operation standards. This is important for communication between technical (design/ engineering) staff in the head-office, regional staff with knowledge of local customs and practices and production personnel on site (if they have access to the system), and to develop teamwork in improving product quality and process efficiency. In time, the involvement of suppliers in the overall effort will also need to be considered.

However, many changes in the culture and working practices of the organisation will also be needed for the effective use of the system. The house-builder will need to bridge the knowledge gap by redefining its role as the system integrator for its industry, in the same way as is increasingly seen as the key function of vehicle and aircraft manufacturers. As Barlow (1997) puts it, it must "have the capacity to 'intercept' technologies and reconfigure them" for its own use. It will need to engage its staff and the supply chain in a critical examination of the build method and nurture 'process thinking' in all its operations to improve quality and efficiency. Some steps have been taken in the Partner Company towards this, and are briefly discussed here.

Quality Action Team initiatives for process improvement were introduced as an early step, modelled on a similar scheme in a car company (Reare *et al.* 1994). Quality Councils are in place in each operating region for sponsoring studies by cross-functional teams. The teams follow the format of the Plan-Do-Study-Act cycle (Deming 1986). About half the employees and a number of suppliers, sub-contractors and site labourers have so far been involved. There have been some notable successes - for example, one regional operating unit has achieved a 50% reduction in defects in the installation of heating and plumbing equipment. In about 20% of cases, the recommendations have been adopted for implementation across the Group. A research project with a group of current and potential suppliers to the industry has also been looking at product re-engineering to improve the 'connectivity' of components for ease of assembly; for example, prototypes have been developed for rapid assembly of internal doors and sanitary ware units without the need for skilled trades. Employee participation has more recently been widened through the introduction of Process Improvement Workshops. These bring groups of staff together in facilitated sessions to study their role in achieving the Company's strategic objectives, analyse the processes they own, set performance standards and develop improvement plans. Pilot studies have been used to standardise and improve a range of critical business processes (e.g. planning of the site layout), delays in which have a significant effect on subsequent site operations, and the methodology has been adopted as a standard business tool by one regional unit. A proposal for a supplier assessment programme has also been developed and is currently under consideration by the Company; the objective is to identify opportunities for improvement in performance (related to quality, delivery and efficiency) and, where necessary, a joint review with individual suppliers to agree on an action plan. These and other initiatives are gradually developing the organisational infrastructure necessary for internalising the process of change and creating an environment for innovation. The research programme on new technology and product engineering is creating the momentum for change. Quality Action Teams and Process Improvement Workshops provide the vehicle for employees (and, potentially, the supply chain) to participate in it. Process documentation provides the mechanism for a rigorous examination of the build process, and then communicating/ training the workforce in the implementation of the new, standardised process.

SYSTEM DEPLOYMENT

BPDS was created using an Oracle database generated from Oracle Designer. The images on the Operation Standard sheets have been primarily produced with digital cameras and then edited using third party image editing software. Initial development was done in a client/server environment, and a web-based version has also been produced for deployment over the Internet or a company Intranet, which provides a more flexible access/ communication route. The latter option is being used in its implementation in the Partner Company, which plans to make Intranet access available to all its building sites. BPDS has been designed to be part of an integrated product knowledge and order fulfilment process. Design of the database is based on an analysis of requirements of key business processes in the house-building sector (product design, configuration and sales, etc).

CONCLUSIONS

The UK house-building industry has often been criticised for the poor quality of its products, and there is evidence of growing customer dissatisfaction. A wide-ranging programme of change will be needed if it is to address these concerns – embrace technological innovation, re-examine its processes and working practices, and start to change a culture that has long been tolerant of failures. It can learn from the experiences of other industries that have had to go through similar adjustments in their strategy and operations. The paper has addressed one important element within this holistic framework of change – the need for formal procedures for process analysis, standardisation of the build process based on identification of good working practices for quality and efficiency, and training/ communication of this to site personnel and contracted workforce. The process documentation system (BPDS) that has been developed has been partially implemented in the Partner Company. There are important considerations in the design and implementation of such a system. The process documents have to be carefully designed to engender process thinking and be informative for its target recipients. The complex applicability relationships that exist between products and processes cannot be succinctly expressed simply through a product hierarchy, but requires mediating modelling constructs for efficient data management. A Total Quality framework needs to be developed to engage employees, suppliers and sub-contractors to participate in process improvement. An integrated business process framework should also be in place for the efficient and error-free operation of the interfaces between product design, build process and order fulfilment;

this will assume greater importance as product variety increases with the adoption of a mass customisation strategy. The process sheets initially developed in the pilot scheme are still in use. These were introduced to coincide with a pilot programme for the use of directly employed, multi-skilled teams for the finishing stages of the build process. The processes developed and the documents were used to train new teams. Clearly it is impossible to separate out the effects of the new working arrangements from that of the process thinking that went into structuring the work, but results so far indicate 50% drop in recorded defects, and the practice is to be adopted by all the regional business units of the Partner Company. BPDS has more recently been used to develop and standardise the assembly processes for the new structural envelope that is currently being introduced. Development and review of the entire process for the construction of houses with the new build technology is also due to commence shortly. Initial emphasis in these applications has been on the examination of working practices but, in the future, it is expected to include regular reviews of opportunities for ‘breakthrough’ improvements with technological and engineering changes.

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