DESIGN FOR MANUFACTURE AND ASSEMBLY

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ABSTRACT

The inclusion of off-site production into construction project delivery offers many benefits but its inclusion frequently results in inappropriate design work. This may be double design work largely due to detailing included in the traditional design process either repeated by the manufacturer for bespoke production or has been undertaken previously during original product design, substantial material waste due to poor sizing for standard components or incorrect design of surrounding structural elements. As the scale and number of manufactured items incorporated increases, the extent of this waste in the design process becomes more significant. To compensate for this, an amended design process is required along with major changes in the design role and the composition of the design team itself. This paper, based on research[3] funded by the UK Government Department of Trade and Industry (DTI) and Engineering and Physical Sciences Research Council (EPSRC) and the experiences of a major mechanical services manufacturer[4], presents a revised design process focused on Mechanical Engineering, showing where and how waste is eliminated and the roles of the various design team members.

KEY WORDS

Design, pre-assembly, off-site manufacturing, process.

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INTRODUCTION

Both construction clients and the Government are placing the UK industry under pressure to become more competitive, contribute more fully to sustainable development and improve the quality of life for both stakeholders and the wider community. Further pressure for the industry to change its approach and practice is arising from long-term shortages in skilled labour. The potential of Standardisation and Pre-assembly (S&P) as powerful antidotes[5] to these issues must be embraced by traditional construction practice. Off-site manufacturing is an important part of pre-assembly and by its nature strives to standardise design and assembly activities (introducing factory production methods).

Much work has been done recently to define the benefits of S&P, the strategic decision making processes and the more detailed evaluative work behind the use of S&P6. One area not yet fully addressed by previous research is the need to re-define the design process and the new role required of designers as more of the construction work becomes modular7. If the use of pre-assembled building components is to increase as advocated, designers must become aware of the need to design for manufacture and assembly (DFMA) and to adapt their practices to more conceptual roles (Pasquire & Connolly 2002). Specifically, Clients8 are becoming less tolerant of the doubling up of design work that often happens, further questioning the production of a traditional design that results in redesign by the manufacturer. The focus of the changing role of designers is the definition of new design processes that are economically sustainable and can fully address issues of customer focus. This area is already quite well understood by some of the major building component manufacturers but only very few designers and the expertise of the former will be a valuable aid. This is a situation unique to construction as the design of components by bodies outside the factory is a unusual concept in other industry sectors, lessons learned here may inform other sectors who wish to move towards more customer specified, bespoke products.

SHORTFALLS IN CURRENT DESIGN PRACTICE

The traditional design process combines architectural concept with technical and engineering specification of all construction component details. In many aspects, the scope of the design activities, obligations and responsibilities (aspects that contribute to design risk) are governed by the conditions of appointment and procurement method which frequently permit or even require, design activities to be undertaken by the contractor, who in turn can pass them on to sub-contractors and manufacturers. This can be justified by the argument that detailed design activities eventually reside with those parties best qualified to undertake them. But by the time this happens, the overall design process has progressed beyond the strategic and

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[5] As advocated by Rethinking Construction and Accelerating Change and illustrated by the continuing UK Government funding e.g. PII 2002 Programme C2 £750,000 grant awarded

[6] MCNS Link, EPSRC, DTI and work by CIRIA principally undertaken at Loughborough University

[7] Modular: used to mean several materials combined into a component before installation. May vary from services connection assemblies through toilet pods to whole buildings; for further definition see Gibb (2001)

[8] Martin Long, Stanhope plc addressing IMMPREST workshop, Davis Langdon Consultancy, London, September 2002

feasibility phases and this second and third hand design activity is continually playing "catch up" to the principal and original design team ideas (see Figure 1).

One outcome of this process is that the detail design is left to the last possible minute with little consideration being given to investigating the level of design detail already available in the market place at concept stage and how this might best be used to improve the project delivery. This is repeated project by project even though there is considerable learning potential within the industry resulting from the repetitive nature of much of the construction process. Additionally the probable negative impact of late design decisions on cost and the reducing scope for changes over the time scale of the project are well recognized.

Traditional design can be described as "designing from first principles" where the design process for each project comprises progressive layering with successive levels of detail until all materials are specified and their incorporation represented on working drawings. Who undertakes this and at what stage in the project varies, with M&E services tending to be detailed much later than structure and fabric elements and usually well into the construction phase. Final fit-out is increasingly forming a separate contract and the relationship of fit-out design to building design may suffer as a consequence of this division.[9]

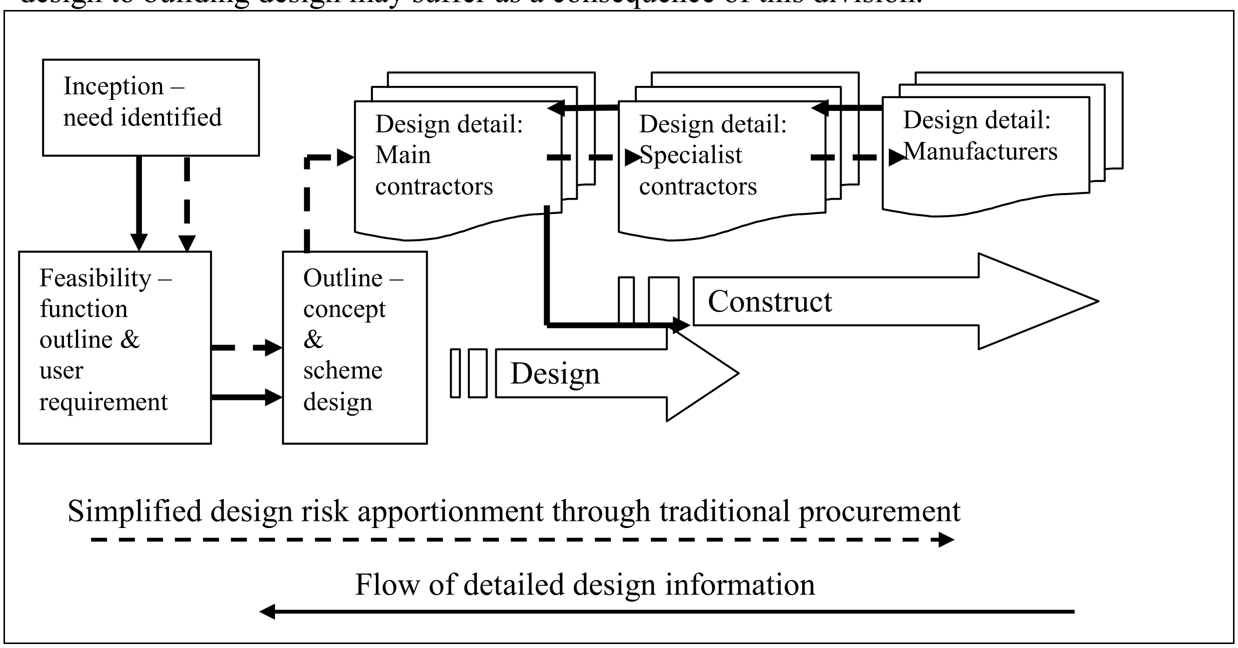

Figure 1: Flow of detailed design information under traditional procurement

Designing from first principles, although frequently constrained by site topography, almost always follows directly on from conceptual activities which are concerned mainly with aesthetics and space. There is little rationalisation activity in the design process when the concept is examined in order to identify project drivers and constraints and optimise the construction process itself even though these might reasonably be expected to contribute to

[9] Design of building structure to maximise use of standard and manufactured fit-out components increases flexibility of building use in post-occupancy phases.

any Value Engineering/Management exercises. Aspects of construction and building design that might affect the optimisation activities include:

1. consideration of standard sizes, not only for pre-assembled components and modules but also such things as plasterboard, timbers, pipe lengths etc. This problem is not merely a result of design activities but also of the construction methods itself where cutting to size forms a major waste item (Tait and Swaffield 2003). This situation is frequently compounded by manufacturers themselves as they may not fully understand their customers and the constraints upon building design as the building designers are rarely the manufacturers' customers (see Fig 1 – this customer is usually a contractor or sub-contractor)
2. use of standard and/or pre-assembled components is already successfully incorporated into traditional design e.g door locks and latches are ready assembled; also some aspects of steel and pre-cast concrete frameworks. Consequently the practice of designing for standard and/or pre-assembled components is already embedded for certain aspects of construction without controversy.
3. too often design is commenced in a traditional manner and subsequently a decision to use standard and/or pre-assembled components and modules is made much later in the process. This results in duplication of design as the manufacturer has either already designed components if a standard product is to be used, or repeats the design process already undertaken by the building design team if product is to be bespoke.
4. it is not just the design of the component itself that must be considered but also the impact of using such components or modules on the remaining building structure and fabric elements at the very least in terms of space, load and construction method and also access for both installation and subsequent maintenance and repair.

It can be seen from this therefore that the concept of design for manufacture and assembly is an extension of the issues of buildability and the solutions to DFMA are therefore similar to those for solving buildability issues. The difficulty of achieving the changes required must not be under-estimated as although the issues of buildability are well known and have been acknowledged for some forty years or more, many of the issues remain and are tied in to integration and co-ordination problems often becoming procurement "footballs" kicked about among the project team.

IMPROVED DESIGN PRACTICE

The improvement of design practice must be driven from two directions, firstly the building designers themselves and secondly improvements within the manufacturers who supply or wish to supply the construction industry. The improved relationship is illustrated in Figure 2 where more emphasis is placed on the earlier stages to ensure a clear project strategy relating to client need (all organisations focused on same customer who is the building user or income generator for the building procurer) with well defined project drivers and constraints. Research undertaken at Loughborough University[10] aimed to identify these drivers and constraints for standardisation and pre-assembly but found that they were generic across all projects. The discussion of the project drivers and constraints in a team environment at the earliest stages of a construction project were found during industry trials to be one of the most significantly useful outputs of the IMMPREST toolkit. Information about these can be found on the web site along with publications, collaborators and purchase of the toolkit.

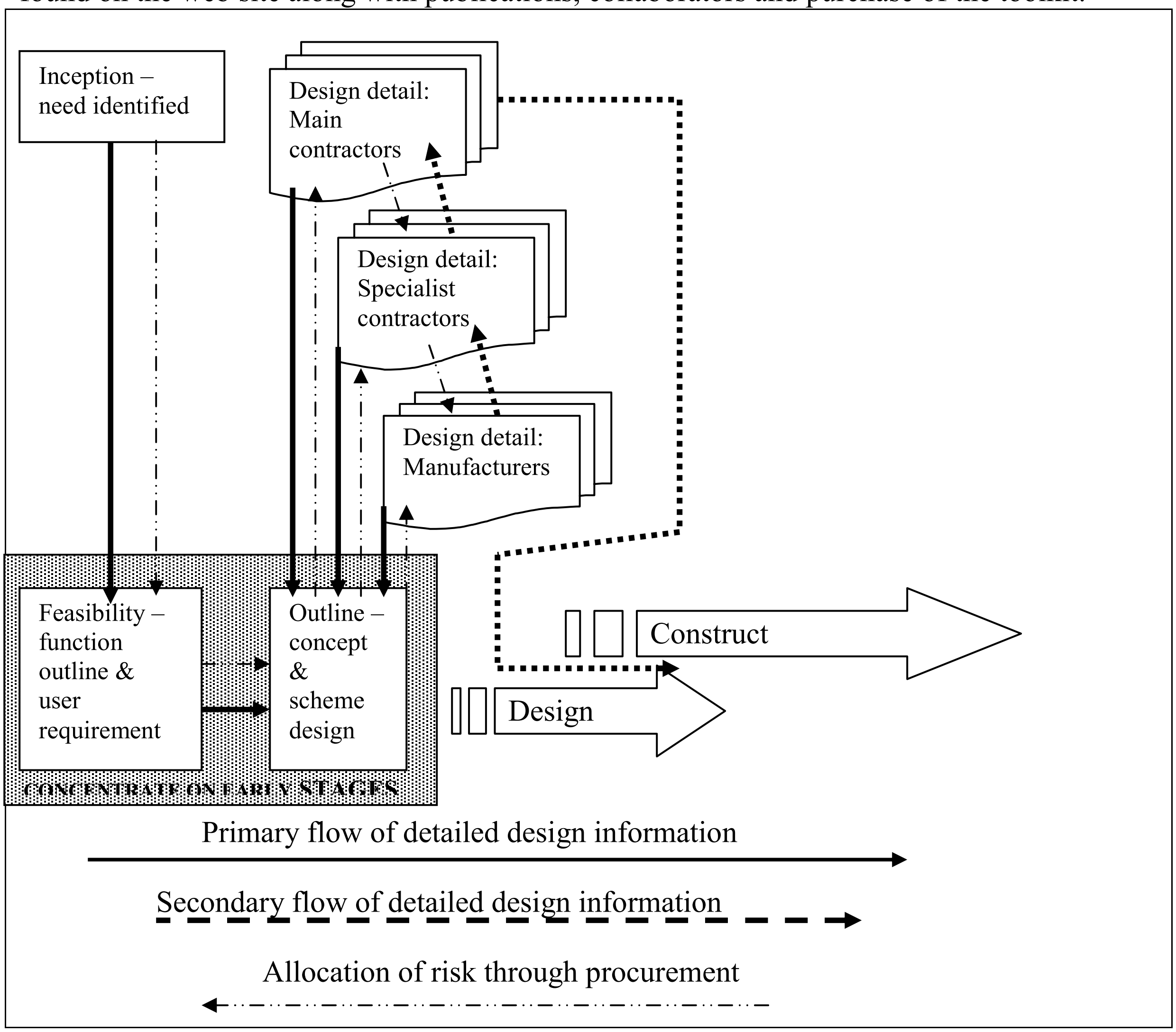

Figure 2: Using Existing Design Expertise From Early Stages

If the building project drivers and constraints can be defined within a set of standards it follows that there is scope for increasing the standardisation of design response also, at least at a detailed level which tends to be hidden from view and often left to technicians to complete. Given the relationship between design detail and buildability it makes sense to use

[10] IMMPREST see www.immprest.com

the expertise of contractors to deliver this detail. However, this design expertise is best accumulated within contracting organisations that view their business as the delivery of a product and see their operations as repeating processes. This encourages a manufacturing approach towards project delivery and draws these organisations broadly into a type of manufacturing. This approach offers opportunities to build on previous experiences, learning from and incorporating improvements each time instead of starting from square one for each project – a feature prevalent in existing project delivery and manifested in the cycle of repeating mistakes, wasteful processes and fire-fighting management practices. There is an increasing trend for UK construction companies to move towards a manufacturing approach for example the product team approach advocated by Taylor Woodrow. If this is the case, and coupled to an increasing use of pre-assembled components and modules, it means a significant change in the dynamics of the design and construction team. This change is results in two major requirements:

a. That designers leave detailed design to manufacturers and become experts in component specification and defining client/user experience
b. That manufacturers (including contractors) provide better product specification and take more care to understand client need and building design constraints.

One outcome of these is that construction moves away from being an end in itself (or a push system) and moves towards the client specified definition of value advocated by Womack and Jones (1996) as the first component of Lean Thinking (towards a pull system).

What is proposed in this paper is not that pre-assembly is a consideration that may be addressed at some point during the design process but that it is a fundamental aspect of the design used as a matter of course and the consideration is then to identify where pre-assembly is not appropriate (pre-assembly is not advocated as a panacea for all projects but most projects will benefit from a degree of standardisation and pre-assembly if correctly incorporated into the design process).

DESIGN FOR MANUFACTURE AND ASSEMBLY

Ensuring design activities optimise the assembly techniques available requires a detailed process. Crown House Engineering in conjunction with a major construction client and its construction team have developed and adopted the following 3 Step DFMA process for mechanical services installations:

STEP 1: GENERIC INTENT

The process relies on the generic intent to use manufactured components as a matter of course at the outset, this drives the strategic development of the project delivery mechanisms. The first part of this strategic development comprises the vision for the inclusion of pre-assembly manufacturing stating the drivers and constraints and the manufacturing deliverables for the project/s. The output of the statement of drivers and constraints is the product guidelines. These guidelines assist in the second strategic activity which is understanding the benefits and limitations of pre-assembly products (the product concept), specifically the differential between specialist products and supplier products.

STEP 2: DESIGN

The design process itself comprises four main activities; firstly understanding the interfaces between the structure and the services ensuring design integration. The component parts of this activity include zonal fixing for optimising work flow, inclusion of specialist supplier information (if not the suppliers themselves), designing the assembly interface with the structure and fabric (frequently includes other pre-assembled components and modules), once designed the interfaces require continuing coordination and the design process itself should be comprehensively mapped (preferably using modified standard approaches to minimise waste and reduce risk), only when satisfied with the completeness of these activities can effective design integration be achieved and drawings be commenced.

The second activity within the design phase concerns the selection of products, components and pre-assembly unit (PAU) systems. This activity should include the understanding and knowledge of the ability of specialists to innovate and advise and consideration should be given to the range and relationship with suppliers. With this knowledge in place, appropriate manufactured systems can be selected and feasibility studies can be commenced.

The third activity in the design phase concerns the development of the design process programme and the tasks within this include the investigation of the manufacturers' requirements, the identification of data flows and specialist inputs. The design process should identify co-ordination activities within the programme.

The fourth activity revolves around the preparation of manufacturing drawings and involves the definition of supplier specifics and the co-ordination of the manufacturing input. The output from this activity are the product programme schedules and the manufacturing activities are then pegged within the process.

INTERIM STEP 2/3

As the design phase switches to the manufacturing process, the activity of component purchase becomes paramount if timescales are to be met. A production flow chart needs to be developed in order to manage the timeliness of component assembly, delivery and subsequent installation.

STEP 3: MANUFACTURING

The manufacturing phase of the process comprises three activities, the first of which is the factory assembly leading to the completed product controlled by production checklists. The subsequent activity of releasing the manufactured components is marked by the completion and signing-off of the production checklists with the third activity being the on-site installation.

DFMA PRINCIPLES

A formal approach to the design process is required in order to optimise the changed process and a solution is illustrated in Figure 3. This shows the manufacturing response pulled as a result of design strategy push. There are six component principles in designing for manufacture, assembly and maintenance as listed in Figure 3.

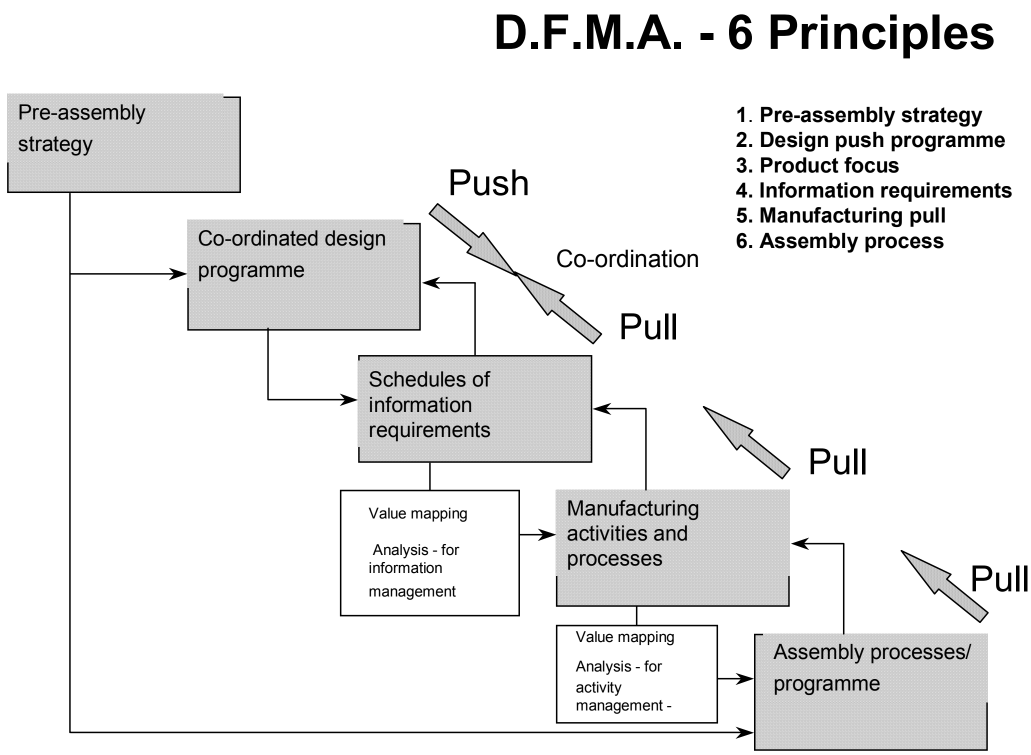

Figure 3: DFMA strategy and principles

D.F.M.A. is the activity of designing how components best fit together to meet manufacturing and installation ideals. This activity should optimise the assembly techniques available and a systematic approach should be developed which considers the inputs and outputs required, the constraints under which the system is operating and the resources available as shown in Figure 4:

MANAGING THE DFMA PROCESS

The process outline above is being successfully implemented by Crown House Engineering and three principal management phases have been identified within a Manufacturing for Construction Implementation plan. These stages and the activities within them are shown in Table 1.

The management process shown in Table 1 provides information for the deign team and clearly explains what is to be undertaken by the manufacturer and when. Armed with this information and involved in this process, the building designers can be confident enough in the process to release a large amount of design activity to the manufacturer and devote their resources to working much more closely with the Client to better interpret their business objectives and the building user experience. This service is perhaps one that would attract a higher fee level or at least the same fee for less resource. The manufacturer undertaking the design process as shown for all products in any case irrespective of whether the building designer does it – it is impossible for the manufacturer to produce products without doing so but the building designer does not need to do it to deliver the building. It makes sense therefore for the building designer to be the one to relinquish the design tasks.

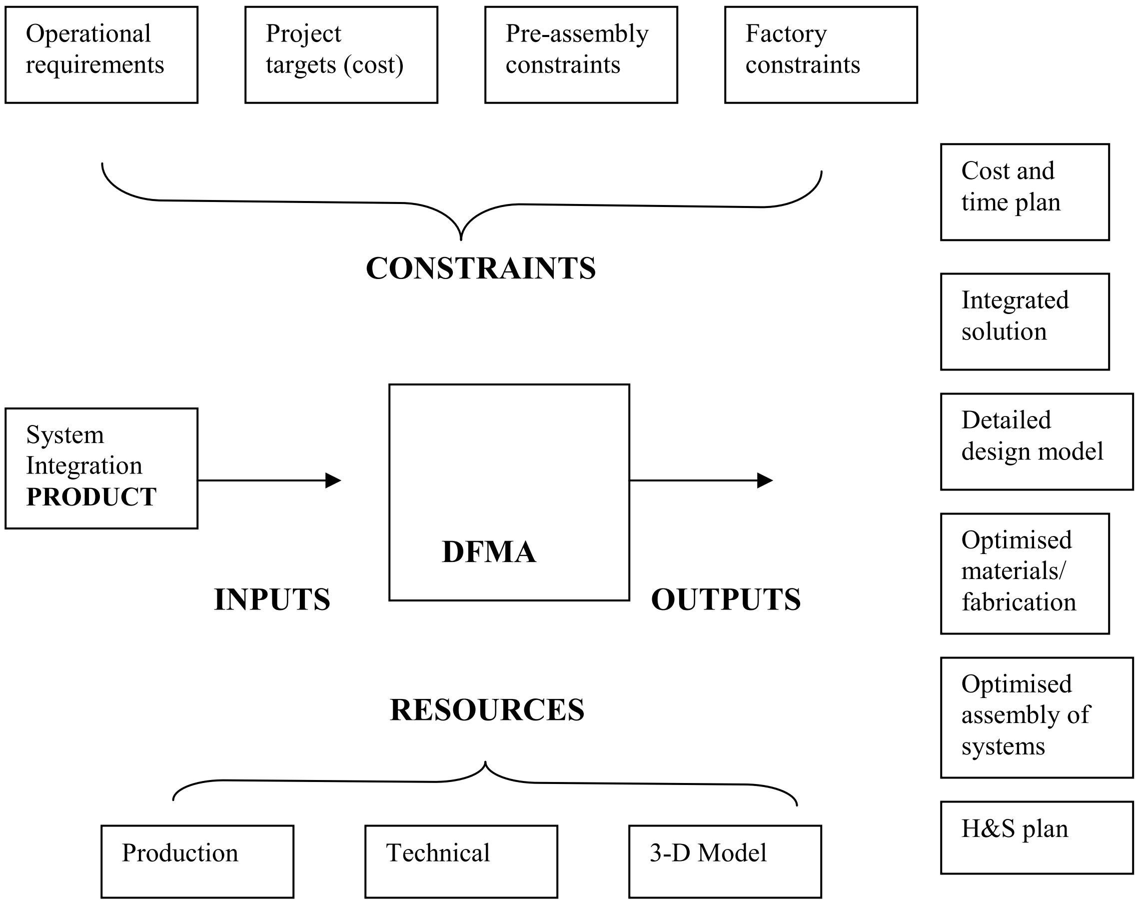

Figure 4: Components of a DFMA System

Table 1: DFMA Management Process

STAGE 1: PLANNING AND CONTROL ACTIVITIES			
Value	**Manufacturing**	**Quality**	**Control**
Integration - work with other suppliers	***Design –*** design information complete	***Quality plan*** – quality plan complete in line with PAU system	***Manufacturing*** – co-ordinated supplier input
Buildability – feasibility study complete	***Capacity –*** can you demonstrate your manufacturing capacity	***Quality control*** – statistical process control in place	***Manufacture*** – flow chart showing supplier input

***Installability* –** JIT study complete	***Production* –** production plan is complete	***Audits*** – audit component suppliers	***Manufacture*** – manufacture sequence
***Safety* –** minimise risk	***Flow Charts* –** flow charts have been produced identifying supplier interface		***Manufacture*** – productivity reporting
***Sustainability* –** minimise waste in design process	***Supply chain* –** identify supplier products		***Manufacturing*** – technical queries complete for manufacture

Stage 2: Production activities

Production	**Component Fabrication**	**Component supply**
Programming – overall assembly in synergy with production programming	***Route card complete*** – all parts required to build are identified	***Route card complete*** – all parts required to build are identified
WIP package agreed – all information complete	***Delivery*** - parts delivery schedules complete	***Delivery*** - parts delivery schedules complete
Manpower – overall resources planned for each PAU/assembly line	***Manufacturing*** – materials supply in synergy with manufacture sequence	***Supplier*** - supplier delivery dates in synergy with manufacture sequence
Information – all information complete to enable route card completion	***Quality*** – all materials in line with project specification	***Quality*** – all components defect free supplier QA assured
Monitoring – quality, efficiency, defects time/cost, predictability, productivity	***Identification*** – all materials identified at supply with WIP number	***Identification*** – all parts identified with WIP number

Stage 3: Assembly and Installation Activities

PRE-ASSEMBLY	**Manufacturingg completion**	**INSTALLATION**
Co-ordination – PAU study strategic fit deliveries; integration supplier scheduling	***QA Qualification*** – QA compliance audit checks document schedules hold authorisation	***Delivery/co-ordination*** – built to sequence method statement for delivery installation connection
Manufacturing flow processing – managed flow capacity plan movement plan supplier co-ordination	***Design performance*** – co-ordinated design and performance checks	***Point of installation complete*** – area complete priority connection ready acceptance system complete teams in place
Kanban control – designated areas, colour coded controlled deliveries to point of build	***Defects free*** – operator verification in process QA, SPC/QA, poka yoke, final inspection	***Installation*** – key install points complete transit items removed hand over to site control
JIT – managed delivery, non-storage environment, co-ordinated delivery	***Fit for purpose*** – pre-commissioning checks, hold points authorised transit robustness checks, QA authorisation templating check	
Maximising efficiency and capacity – productivity, efficiency, safety, quality, cost, delivery		
Established KPI's – design, installation, service, defects, predictability, time/cost, safety, profitability, productivity		

CONCLUSIONS

There are always going to be projects for which standard and pre-assembled components are not appropriate, however, the constrains being imposed by Clients, Government and the lack of labour will push an increasing amount of the construction work into off-site production. In order to incorporate off-site production into the construction, major changes in the composition of the design team are required along with the grasping of a more conceptual, customer focused role for designers who need become experts in component specification and delivering user and customer delight.

Manufacturers to are also required to better understand the drivers and constraints of the building design and construction process and revisit their production processes accordingly, specifically the agility required to meet client design objectives, reducing lead times and providing easy access to component specifications and standard details. Communication between designers and manufacturers must be greatly improved to enable designers to select appropriate components easily and simply better integrating manufactured systems to traditional construction.

Benefits from DFMA will include a more streamlined and less wasteful design service for Clients from consultants and manufacturers. This improved design process will result in more integrated and co-ordinated construction processes, increasing quality, reducing conflict and facilitating the drive towards Egan's seven targets for improvement. In turn, a more concentrated focus on user experience and delight will deliver better buildings thus benefiting users and improving quality of life all round

In total, all this will highlight the view that buildings are enablers of clients businesses and that a lean construction industry delivers value in terms of customer delight (customer in this case means the building user or construction clients' own customer) at best cost to the industry.

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