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Standardization and pre-assembly – distinguishing myth from reality using case study research

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Standardization and pre-assembly (S&P) are not new, but their application and their drivers, pragmatism and perception, need to be considered in the light of current technology and management practice. There are lessons to be learned from a historical review, but there are also numerous myths that must be dispelled: houses are not cars; maximum standardization is not always the answer; and, S&P do not have to cost more. Steven Groák worked with the author on the research project 'Adding value to construction projects through standardisation and pre-assembly' funded by CIRIA (Construction Industry Research and Information Association). The CIRIA project, which forms the basis of this paper, aimed to produce a review of the subject and guidance for clients and project teams through a comprehensive literature review, expert workshops and case study research. The paper defines S&P, discusses past, present and future applications (providing case study evidence) and presents the key benefits and implications of the optimized use of standardization and pre-assembly.

Keywords: Standardization, pre-assembly, drivers, benefits, implications

Introduction

Over the years and under various guises, standardization and pre-assembly (S&P) have been used on construction projects with a view to improve value for money. The approach is not new and, in most senses, not innovative. In fact it seems amazing that S&P are so poorly understood by many involved in the construction process, especially those involved in procuring construction projects in the UK, as demonstrated by the author in a major interview survey of construction clients (CIRIA, 2000). This has lead to the inclusion of S&P in a number of strategies in attempts to cure the ills of the construction industry.

Various exponents from previous eras have presented S&P both as an expediency and as a design philosophy (e.g. White, 1965; Russell, 1981; Gropius and Wachsmann in Herbert, 1984). Although the basic principles have not changed, what is needed is an up-to-date interpretation of how to optimize their use, and this debate is brought up to date in this paper. As long as key players claim that they do not use S&P (even though it is endemic in all construction projects) and as a result fail to manage its application effectively, the potential benefits will not be realized. There has also been a recent increase in interest in S&P both in the UK and elsewhere, with a number of projects and publications (e.g. BSRIA, 1998; Sarja 1998; Gibb, 1999; CIRIA, 1999, 2000). Sarja in particular provides a useful international review of the state of the art in open industrialization.

In his book *The Idea of Building*, the late Steven Groák commented that he was 'perplexed – but enticed and vastly entertained – by the changing problem of how we mesh, perceive, describe, adjust, redefine or operate for practical purposes the jangling mixtures of building design, building technologies, building science, building production and building use'. He

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believed that 'their relationship would continue to change, but in ways which would give greater priority to the making of built forms and to the services they offer' (Groák, 1992, p.5). Groák was dedicated to observing and reviewing this change critically, as well as contributing to its formation. It was in this context that the author worked with him on a number of S&P research projects.

The CIRIA (Construction Industry Research and Information Association) research project and Report entitled *Adding Value to Construction Projects through S&P*, focused on value to be gained from the application of S&P. The research method included workshops, expert interviews and case studies over an 18 month period. The workshops, as the main data gathering activity, covered S&P principles and strategy, volumetric and non-volumetric pre-assembly, modular building, and component and procedure standardization. The case studies are summarized later in Tables 1 and 2. The work involved more than 60 experts representing the views of clients, contractors, designers and suppliers, and has resulted in two key publications (CIRIA, 1997, 1999). These reports introduce S&P, their implementation in construction projects and their contribution to achieving value for money. The case for S&P, namely predictability and efficiency, is argued and implications for projects and the whole industry are presented. Lessons from non-construction sectors and other countries are brought to bear on construction. The report presents a simple, standardized procedure for optimizing S&P. The report concludes that deliberate, systematic use of S&P, started early in the process, will add value to projects by increasing predictability and efficiency. This work is now being developed in a further CIRIA project to develop a client's guide for S&P optimization (CIRIA, 2000).

The CIRIA project forms the framework for this paper along with review information from Groák's *The Idea of Building*. The paper defines S&P and their drivers, pragmatism and perception, as they are understood at the turn of the millennium. Through a brief historical and contemporary review several myths and legends are exposed, and the realities of modern applications of S&P are presented.

S&P – past, present and future

Developing a better understanding of S&P

Standardization is the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability. Some items are standard by their nature (generic standardization), or their country of origin (national standardization). Both clients and suppliers may have standard processes or products. As a minimum, project teams should do what ever they can to standardize across the project. Benefits that can be obtained from such standardization during the manufacturing phase can be seen from Figure 1.

Historically, those taking standardization seriously (e.g. Gropius in Russell, 1959, p.48) have always struggled to resolve the conflict between uniformity and variation, between maximum standardization and flexibility. This conflict has still not been resolved: it remains as a tension that sometimes leads to design impotence, but should be used to ensure optimal implementation. Standardization works by ensuring accurate fit and interchangeability of components. Thus the most important area for standardization is actually the interfaces between the components rather than the components themselves.

Many different terms are used to describe the process of pre-assembly. Often they are used inappropriately and with little understanding, both historically (White, 1965, p.3) and today (CIRIA, 2000). The following definitions have been developed by the author since the CIRIA project and seek to bring some cogency to the use of terms.

- *Component manufacture and sub-assembly*
  Many components used in construction are actually sub-assemblies (e.g. door furniture or light fittings). This category includes all small-scale sub-assemblies that would never be considered for on-site assembly in any developed country. Their use is outside the scope of this paper.

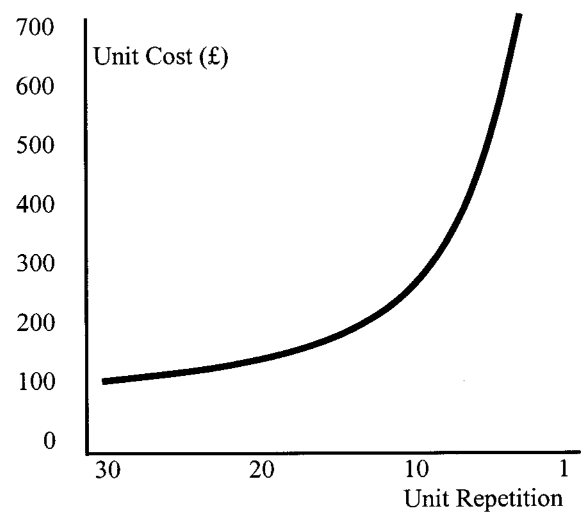

Figure 1 Relationship between unit cost and unit repetition (standardization) for precast concrete cladding (Courtesy of Trent Concrete; adapted from Gibb, 1999)

- *Non-volumetric pre-assembly*
These items are assembled in a factory, or at least prior to being placed in their final position. They may include several sub-assemblies and constitute a significant part of the building or structure. Examples include wall panels, structural sections and pipework assemblies.
- *Volumetric pre-assembly*
These items are also assembled in a factory. They differ from non-volumetric in that they enclose usable space and usually are installed on-site within an independent structural frame. Examples include toilet pods, plant room units, pre-assembled building services risers and modular lift shafts.
- *Modular building*
These items are similar to volumetric units, but in this case the units themselves form the building, as well as enclosing useable space. They may be clad externally on-site with 'cosmetic' brickwork as a secondary operation. Examples include out-of-town retail outlets (McDonald's Drive-Thru), office blocks and motels (Forte, Friendly, etc.) and concrete multi-storey modular units used for residential blocks in Korea (now also used for UK prison buildings).

These definitions were developed independently by the author following close evaluation of contemporary applications. However, it is significant that they agree very closely with historical definitions, despite the changes in technology. White (1965, p.3) describes four degrees of prefabrication as 'pre-cutting; panel fabrication; volume enclosing sections; and manufacture of complete dwelling units as the ultimate'.

History and philosophy of S&P

'Some components have been standardized over centuries, such as bricks and tiles, and there exists an enticing set of myths to justify each standard. The use of modular frameworks has existed for centuries (e.g. in Europe since the early Renaissance). However, the real drive to combine standardization with systematic building grew with the development of the off-site fabrication shops and the factory-based building component industry' (Groák, 1992, p.134). Having reviewed the historical S&P debate, this paper contends that there are two fundamental drivers for S&P, namely: pragmatism – industry response to an urgent need combined with a lack of resource; and perception – client and public reaction to a prevailing design philosophy.

Industry's pragmatic response to an urgent need encapsulates the wax and wane of S&P since the start of the industrial revolution. The export of prefabricated houses supported the colonial expansion of European nations, where there was an urgent need for shelter and a distinct lack of locally available materials and labour (at least to suit the tastes of the Europeans). In the mid-19th century Brunel developed standardized, prefabricated hospitals for the war in the Crimea. The army had the urgent need with no local solution available. UK fabricators responded to the need for housing combined with the acute shortage of skilled labour following the two world wars (after 1918 and 1945). Herbert (1978, p.2), commenting on historical applications of S&P, recognized this motive for S&P where 'local demand, generated by unusual circumstances, exceeded the local capacity to supply the buildings so urgently needed'.

In some parts of the world (e.g. Singapore) there has been a recent urgent need for housing that has been addressed by S&P. However, in Europe the residential need is not for significant numbers of low-cost units and, as such, the urgent need no longer exists. In Europe the needs have changed, with society now dominated by leisure and travel. Interestingly, it is in these areas of need that contemporary S&P is seeing its main opportunity (e.g. McDonald's Drive-Thru, Whitbread public houses, Forte hotels, BAA airport developments, and fuel outlets for Shell, Esso, etc.) compared with houses and schools during the last period of UK S&P growth in the 1950s and 1960s. Opportunities for S&P in the UK residential sector still appear limited, despite positive experience from other countries such as The Netherlands and Japan (Gibb, 1999).

Alongside this pragmatic response lies the issue of design philosophy or, more particularly, clients' and the public's perception of it and reaction to it. Historical proponents of S&P, such as Wachsmann, Gropius and Le Corbusier, approached the issues from the angle of idealistic design purity: 'better architecture for a better world' (Herbert, 1965, on Gropius). This paper argues that the prevailing public mood at that time, notwithstanding a few traditionalists, was to support these ideals as part of the 'brave new world', where everything new was to be espoused and everything traditional denigrated.

However, client and public perception of design has changed. Emphasis now falls on achieving value for money, zero defects, minimal waste and achieving minimum environmental impact. Innovation plays a leading role in both the recent UK Government-sponsored reports on the way forward in achieving the targets set for construction (Latham, 1994; Egan, 1998). S&P are seen as one of the ways that these targets can be met. This paper also contends that today's public is reluctant to accept the modernist philosophy. Instead they demand maximum choice and appear to be comfortable with pre-assembled buildings looking as though they are produced conventionally (CIRIA, 1999). This has led to the demand for mass customization rather than mass production. This is where the benefits of mass production can creatively be combined with systems that offer greater choice for the individual customer, provide improved control of the total construction process, and flexibility of assembly options. This demand can be met through developments in manufacturing, such as digitally controlled machines, automation and electronic data interchange.

CIB international Working Commission 24, Open Industrialization in Building, supports this view, stating that 'the technical, architectural goals and realization of industrialized building changed most during the 1980s and 1990s. The current technology is flexible for individual architectural designs, allowing easy alterations during use, future changes and modernization. For this aim, systematic modular design and products are applied, including dimensional modularity, tolerance system, compatible joints and use of modular products.' (Sarja, 1998, p.15).

Groák (1992, p.124) explains that the 'extensive system of factory-produced materials and components has changed the building process out of all recognition. Designers can assume the availability of off-the-shelf components; they can also assume the availability of special variations from those factories, based upon the stock designs and expert manufacturing advice.' He found that the 'result has been a tendency to greater use of prefabricated components, standardization of construction and the development of work packages – distinct elements of the building designed to suit a given sub-contractor/manufacturer'.

It is important that we learn from history. The CIRIA project used several historical case studies to describe how the application of S&P has developed over the years. These are described in Table 1 along with the key lessons.

Table 1 Historical case studies from CIRIA S&P research

Project	Main S&P application	Key lessons
Crystal Palace, London 1851	3 storey exhibition hall Factory-made iron, timber and glass components Re-located from original site	First project to closely link site and factory processes Maximum standardization Drastic time and cost savings On-site painting then took considerable time Pre-assembly allowed re-location and re-erection Project team make up very different to today – more emphasis on individuals
British Hospital, Renkioi 1855	Crimean war hospital Prefabricated timber units, shipped from UK to Turkey Modular layout and some details were standardized	Cheapest and lightest building constructed up to then Overall project duration reduced to 6 months Small, skilled erection team ensured quality but took time Allowed controlled construction in an unknown location Approach developed for several further applications Process driven by committed individual (Brunel)
Royal Albert Bridge, Saltash 1859	One of the earliest extant examples of pre-assembly Wrought iron trusses assembled on the banks then floated into position	Most economical engineering work in existence (Client) Pre-assembly was considered right at the start Careful and detailed planning is essential Pioneer project for many future bridges
Charles Eames House, USA 1949	House built entirely of mail-order components Unashamedly part of the modernist ideology	Use of standardized components allowed a cheap, swiftly erected building and a successful permanent house Principles not embraced by industry Public did not like the materials
CLASP, UK 1957 to date	Standardized system for educational buildings Lightweight, pin-jointed steel frame, lattice trusses, precast slabs	Main success due to the scale of implementation Originally a solution for subsidence but used widely Overall timescale reduced by 18% Main cost savings from less labour, pre-contract input, contract periods, cost over-runs and delays Still in use after 40 years and many modifications

Myths and legends of S&P

Houses are like cars

For the last few years there has been a clamour to draw parallels between automotive manufacturing and the production of buildings. However, this comparison is not new; for example, Gropius argued that 'industrial production of complete buildings could be analogous with the mass production of the motor car' (Herbert, 1959, p.17). However, although clearly there are building lessons to be learned from much of the manufacturing sector, many of the trite comparisons are hard to substantiate. For example, Groák (1992, p.123) states that 'buildings are fixed to the ground, which means that we have to have a mobile industry, an industry which creates a temporary factory to which materials, machines and people are transported. It means that for each project a unique pattern of linkages with materials suppliers and component manufacturers has to be established for all the flows. The common workplace for the assembly of the building leads to a series of confusions characteristic of this process.' With a typically provocative remark Groák adds that 'this interest in the car analogy probably appealed to those who prefer walking around a warm, dry factory to struggling across a building site on a cold damp evening'. He then adds: 'despite the fact that cars can be sold for around ten times as much as houses, on a cost per square metre of usable floor space, there has been a constant assumption that they can be equated, and therefore that we should transfer work from the house-building site into factories.' Gann (1996) makes a similar point, stressing that there are 'limits to which manufacturing techniques derived from the car industry can be applied to manage the assembly of wide varieties of component parts needed to produce complex customized products (such as buildings). Manufacturers must trade-off the need to achieve economies of scale in the production of standardized factory parts with economies of scope in various stages of assembly in order to provide flexibility to satisfy consumer choices.'

Notwithstanding, there are real lessons that can be drawn from the manufacturing sector, and in particular from the car analogy.

- Mass customization must replace mass production as the modus operandi because technology can now deliver the choice that clients demand
- The customer's needs and desires must be identified and addressed; this will include the need for customization and the offer of choice
- Most customers will accept that hand-crafted one-off products, if desirable, are likely to cost more and take longer
- Most customers are interested in the end product (the building, or car) but rarely concerned about the processes involved
- The performance of the product (for as long as the customer has it) is as important as its looks
- Customers are interested in value for money, although few can really elucidate exactly what that means
- The supply chain must be acknowledged and managed
- The whole process must be focused on producing an excellent end-product
- Appropriate pre-assembly and outsourcing of components and sub-assemblies is useful, provided that the process is subservient to the delivery of the end product (the tail must not wag the dog)
- Interchangeability and surety of fit will demand close attention to interface or connection design, manufacture and assembly

Maximum S&P is always for the best

Groák (1992, p.34) argued that 'there is a school of thought which promotes concepts of buildability, or constructability in the USA, based on the attempt to bring a greater awareness of production priorities into the design process. Despite this admirable intention, it is flawed by the implicit assumption that, for one design, there is only one optimum production method. This does not properly recognize the extraordinary variety of production units – and their flexible combinations – in the building industry.' Maximum S&P is not the only solution to every situation. Consider, for example, the alternative approaches of apparently similar clients BP and Esso in their upgrades of forecourt facilities. One client has gone the route of fully volumetric modular, with the other preferring to use flat-pack site assembly. Clearly there is a balance between maximum off-site fabrication and the additional costs of transportation (especially where some of the units are largely empty) (Gibb, 1999).

Furthermore, Gray (1998, p.145) comments that a 'wholesale switch to standardized components is unlikely to occur unless there are some major changes in design policy and these will only occur if there is a major constraint on cost or construction resource in a period of boom'. He also considers that 'stability of demand which would suit maximum standardization is only possible by limiting choice, which the UK has so much of and is unlikely to give up, or increasing demand, which is closely allied to the overall economy and therefore probably is not a viable strategy'.

Herbert (1959, p.21) argues that, contrary to common perception, the modernist architects of the first half of the 20th century did not argue for complete standardization and prefabrication, largely due to their desire for flexibility: 'It is the nature of the part to provide standardization and uniformity. It is the nature of the whole to provide unique, specific combinations, that is, variation.' The ideal is one of optimization rather than maximization. Furthermore, the Japanese, often cited as the leaders in the use of S&P, particularly in the residential sector, actually standardize and pre-assemble sub-units which, when installed on site, make up rooms of differing sizes. The final building is designed such that it is hard to see that it has been pre-assembled, or that it is made up of standardized units (Bottom *et al.*, 1994; Gibb, 1999).

Standardization means standard (and therefore boring) buildings

This was one of the most talked about topics in the CIRIA research, with vehement support both for and against. Clearly there are historical examples of building systems that have been shown (at least judged by the taste of many) to produce boring standard solutions. With aesthetic style being largely a matter of subjective opinion, many also write-off the work of the McDonald's team with their Drive-Thru restaurants. Such a dismissive approach, however, misses the main point of a single-minded client very sure of its business case, not being side-tracked into trying to obtain architectural awards. Actually, as a design item, judged by the standards of any other industry sector, these modular buildings would score very highly.

Furthermore, when considered in a broader sense, standard components can be used to great effect to produce customized solutions. A classic historical example is the Charles Eames house that was constructed entirely from standard catalogue components (Table 1). Also the Georgian residential design system involved considerable standardization, yet has produced houses that many aspire to own and live in with the word 'boring' far from their minds.

The argument has already been made that although the parts may be standardized, the whole must provide variation: customized solutions from standardized components. This may also be why many suppliers actually play down the fact that their products are standard, believing that the customer wants to think that they are designed specifically for their particular project (but also perhaps because the supplier believes a premium price could be charged for special products). In some parallel research work (IMI, 1999) in the cladding sector, Gibb established that many so-called bespoke cladding systems (designed specifically for the project) are actually little more than adaptations from previous projects. A mechanical services supplier, working in the UK and several Scandinavian countries, has contrasted two approaches to standardization where in Scandinavia the approach is 'if you can't see it, standardize it' but in the UK it is often 'we must start from scratch for everything'.

However, there is still a significant lobby, particularly amongst architects, that argues against standardization in design. Fox and Cockerham (2000) describe four different types of design category.

1.	Bespoke	No standardization except loose parts and materials
2.	Hybrid	Standard sub-assemblies with bespoke interfaces
3.	Custom	Standard components up to assembly level
4.	Standard	Standard components with standard connections

They argue that few buildings fit into the standard or custom category, and as such they claim that 'Egan's lean thinking recommendation is less applicable to architecture than an ability for agile thinking'.

It appears that the industry's dilemma over the worth, or otherwise, of standardization is creating a smoke screen that makes accurate evaluation of success difficult to achieve. By concentrating on excellence in design, S&P can produce exciting, innovative buildings that could not be seen as boring (e.g. Peabody Trust, Murray Grove, Hackney, 1999).

More or less? – The cost of pre-assembly

'The use of elemental cost analyses, based on historical data, presents many problems when new designs and/or new production methods are introduced. In particular, it is insensitive to the complexity of construction method' (Groák ,1992, p.103). This is particularly the case for S&P, where many of the benefits are realized elsewhere in the construction process (e.g. reduced site labour and associated costs). Taking an elemental view by considering the building element in isolation, it is not surprising that pre-assembled units may appear more expensive. For example, the overheads and set-up costs of the factory must be covered, whereas for site works the equivalent costs are often 'lost' in the principal contractor's preliminaries.

Increased productivity in the factory should bring cost savings along with economies of scale. However, Groák found that 'the realities of manufacturing production for established systems were that the manufacturer had to wait on orders via the general contractors. Supposed economies of scale were rarely realized, although better prices through bulk buying were achieved' (Groák, 1992, p.135). Furthermore, in line with a free market economy, this paper argues that many manufacturers and suppliers seek the maximum price that the market will sustain. Therefore the tender prices quoted may not reflect the actual costs, and therefore hinder sensible comparison with conventional construction.

Realities of standardization and pre-assembly

The benefits and implications of optimized standardization and pre-assembly

The CIRIA project found that the greatest benefit was gained when S&P were used together, and this section describes the benefits and implications of implementation. The CIRIA research included a number of contemporary case studies. The research team was keen to demonstrate real applications 'warts and all', rather than just present the theoretical benefits. The case studies are described along with the key lessons in Table 2. It was found, however, that in practice the benefits claimed were rarely specifically measured, but were based on client or project perception. The subject of developing an effective measurement method is being addressed in further work by CIRIA (CIRIA, 2000).

Standardization of processes and procedures enabled project teams to streamline the overall construction process, which was claimed to reduce wasted effort and project team resource. This potential existed even on individual projects, but clearly could be even greater for larger clients with repeat orders. Contemporary business systems, information technology and management techniques enabled standardized processes to be more sophisticated than had previously been the case, thus addressing historical concern about inappropriate, bureaucratic procedural standardization. Projects claimed that standard procedures increased confidence in project outcomes as stakeholders became more familiar with these processes (e.g. BAA's Genesis project, see Table 2).

Standardization of products and components offered benefits from continual improvement as found in other industry sectors but often not realized with the one-off, unique project approach in construction. Interviewees considered that safety and productivity performance should improve as off-site and on-site personnel become more familiar with the materials and components. The fact that they are tried and tested was believed to control risk and increase reliability, both during the construction process and throughout the life of the building or facility: the building should perform reliably, be more easily maintained and require fewer spare parts. However, as explained previously, it was thought that benefits from repetition and mass production may not be realized and, even if they were, they may not be passed on to the client.

It was found that, because pre-assembly brought the construction site into the factory where the environment was more controllable, safety, productivity and quality could all be improved. There should also be less waste and less impact on the environment. However, once again, there were few examples of metrics to enable effective measurement. Furthermore, these benefits will be realized only if the traditional site-based practices and culture are not merely transferred to the factory but rather completely changed to reflect the manufacturing culture. The CIRIA work found that, by manufacturing and pre-assembling units before they would be needed on site, confidence that the project outcomes would be achieved was increased. This was particularly the case in terms of predictable price, cost and programme.

Even though pre-assembly changed the site processes and could actually increase the hazards in some cases (for example increased craneage), the installation processes, by their very nature, had to be thoroughly planned. It was claimed that this reduced the need for on-site problem solving and enabled site activities to be managed more effectively (e.g. Chek Lap Kok Airport, see Table 2). Furthermore, pre-assembly made some projects viable when they could not have been built had they relied solely on site work (e.g. RAF Mount Pleasant, 2nd Severn Crossing, see Table 2).

In summary, the main potential benefits of S&P were found to be increased predictability and efficiency. S&P used together were seen to facilitate better management, but also to require better management. Understanding and commitment to S&P by all parties was considered vital. Design decisions generally had to be made earlier than for conventional construction, and critical information had to be established at the earliest possible stage. In an effort to address historical criticisms of S&P, project teams worked hard to ensure that S&P increased design choice, facilitated controlled innovation and ensured work of quality, aesthetic appeal and distinction. Managers had to be trained to control a manufacturing process that was considerably different from the on-site, often ad hoc management of conventional construction.

Closing thoughts

This paper has defined standardization and pre-assembly (S&P) and has presented a historical and contemporary review of S&P applications. It has claimed that success or failure of standardization and pre-assembly will depend on the pragmatic response of industry to an urgent need, and industry's ability to predict what the developing needs will be. The CIRIA work found that clients' perception of the prevailing

Table 2 Contemporary case studies from CIRIA S&P research

Project	Main S&P application	Key lessons
RAF Mount Pleasant, Falkland Islands 1985	Flat pack and volumetric units for residential and welfare facilities – shipped from UK	Pre-assembly was the only viable option Significantly reduced site labour force Efficient use of shipping capacity Early weatherproofing of units essential On-site finishing was time consuming
Kansai Airport, Japan 1993	Structural steel wings, shipped from UK in containers Pre-assembled on-site before installation	Project not possible without pre-assembly Extensive use of IT benefited project Concentration on manufacturing accuracy essential 'Bespoke' details but still treated as a manufacturing process
Vintners Place, London 1993	High-quality volumetric office washrooms for a speculative commercial building	Pre-assembly has benefits even with little standardization Pre-assembly suits projects with a tight construction programme, restricted site space, high quality finishes and complex construction interfaces Early involvement of manufacturers is essential
Second Severn Crossing, UK 1996	Precast concrete bridge piers and deck sections Steel/concrete composite deck units	Pre-assembly minimized on-site work in the river Time is needed to plan for standardization Existing costing systems favour minimal material solutions ignoring benefits of standardization Detailed, thorough planning is essential
Bathroom units, Denmark 1998	Volumetric precast concrete bath and shower room units used for residential and institutional buildings throughout Europe	Application is accepted as the norm in many countries Basic system has been developed over many years Details change for each project but system is standard Productivity, quality and health better in factory
Genesis project, Heathrow 1998	Multi-storey car park Part of a framework agreement Extensive use of standard systems Pre-assembly maximized Benefits measured	Simple buildings can use 100% S&P Repeat-order clients can obtain additional benefits Measurement of S&P is difficult, but beneficial The variable cost is in connections and site work 3D computer modelling aids S&P application
Chek Lap Kok Airport Hong Kong 1998	1998 – 129 (36 m x 33 m) structural steel roof units for airport terminal building, shipped from UK then pre-assembled on-site	On-site pre-assembly suitable for 'large' sites Optimal balance between remote pre-assembly and transport costs Health & safety risks reduced by less work at height Handling logistics limit extent of pre-assembly
Modular office buildings, UK Circa 2000	Whole buildings factory-assembled One brick-clad on site, the other left as factory-finished	Standard modular buildings benefit 'one-off' clients Cost and programme were predictable and less than conventional (<10 weeks from contract to completion) Variations are possible but limited and have cost and programme implications
Modular buildings, UK Circa 2000	McDonald's Drive-Thru; schools and hotel applications of modular buildings	On-site time significantly reduced (26 wks to < 2 wks) Standardized units enable rapid design/construction of on-site elements (drainage, foundations etc.) Pre-delivery test and inspection is advised Factory allows better productivity and quality Variety through different unit configuration and finishes

design culture has led to their demand for customized solutions, and they will accept that these can be achieved using standardized products and processes combined with pre-assembly. It seems that very few clients actually strive for S&P in itself. Instead, most desire to be seen to innovate, to have efficient, cost effective projects while caring for the environment and catering for the lifecycle of their projects. Where S&P can demonstrate that they will achieve these goals then they will be used. Lessons can be learned from the manufacturing sector, but houses are not cars and close comparisons should be treated with caution. By concentrating on excellence in design, evidence suggests that S&P can produce exciting, innovative buildings that would not be seen as boring and would be cost effective, providing value for money throughout the project lifecycle. However, it was recognized that often in the past the end result has fallen short of this ideal.

The CIRIA work found that S&P, if optimized and managed effectively, can help to overcome some of the costly unpredictabilities and resulting inefficiencies of the construction industry. It can increase confidence that value for money and a satisfactory performance to programme can be achieved, risk controlled and reliability increased. In addition, safety, health, productivity and quality performance should all increase. However, these benefits are not automatically achievable. They require the understanding and commitment of the whole project team and early agreement of critical information. Furthermore, project management must respond to the different culture produced by replacing conventional construction activities with a manufacturing process. Failure to address these issues effectively may even result in increased time and cost and desired project outcomes not being achieved.

Steven Groák has played an important role in developing a realistic attitude to S&P. The fact that he is not able to continue his work will be to the detriment of those in the industry who refuse to accept trite homilies but rather strive for real understanding of complex processes.

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