STANDARDIZATION OF BRICKWORK CONSTRUCTION: IDENTIFICATION AND MEASUREMENT OF STANDARD PROCESSES

N. Dawood, B. Hobbs and A. Fanning

Centre for Construction Innovation Research, University of Teesside, Middlesbrough, UK

This paper addresses a research project (funded by EPSRC and DETR through MCNS) that is concerned with the "re-engineering" of the business process of brickwork construction. The prime objective of the research work is to develop suitable strategies for the incorporation of standardized procedures and design features, both for on-site construction and for prefabrication of brickwork.

The research project addresses the scope for improving the efficiency of construction involving brickwork by harnessing the synergy between technological developments in the areas of design, fabrication and site construction techniques, and business process developments in supply chain and materials management.

This paper covers the review undertaken to assess the current state-of-the-art in masonry off-site prefabrication (P-F) and on-site standardization and proposals for re-engineering business processes. This review has been carried out through meetings, interviews and site visits combined with a review of research and practice publications.

A number of key performance indicators have been developed to bench mark proposed processes and have been discussed in this paper.

Keywords: brickwork, key performance indicators, process modelling, productivity, standardization.

INTRODUCTION

This research project is concerned with the rationalization and optimization of brickwork construction activities and productivity. In general, current construction processes are wrapped around the finished product. In comparison, manufacturing products are driven through standardized processes which lead to a reduction in ambiguities, time and waste.

Four recent reports were significant in establishing the general background to this research work. The Construction Industry Research and Information Association (CIRIA) Snapshot document highlights the effectiveness of positive standardization, controlled pre-assembly and cost effective modularization. The Constructing The Team report (Latham 1994) objectives reinforce the CIRIA findings and the point that the Construction Industry should reduce waste and deliver superior products. The Masonry Industry Alliance (MIA) through the Masonry 2007 (M2007) report, sets out the criteria to meet these objectives. It specifically highlights the need for development of meeting clients needs, maximizing market potential and, as the 'Re-thinking Construction' Report states improving the process (Egan 1998).

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Bricks may be regarded as the ultimate standardized component, and they are ideally suited to the production of customized solutions in building, particularly for the external walls of housing and for a wide range of other larger building types. Facing brickwork provides a visually attractive and durable external building envelope that is being used increasingly as a means of satisfying client needs for attractive and environmentally acceptable buildings with a high quality image. Their principal drawback is that, with very few specialized exceptions, the construction process is currently site-based and labour intensive. This leads to quality problems, long construction periods and inefficiencies, frequently associated with weather conditions and the difficulty of implementing reliable materials storage and construction quality control systems under such conditions. There is also a growing skill shortage in the area of traditional brickwork construction. Standardized procedures and products of brickwork prefabrication should ultimately lead to speed, reliability, certainty, and durability and energy management.

The objective of this paper is to introduce and discuss the findings of this research project and raise awareness to the potential associated with brickwork standardization and pre-assembly methods and techniques. The findings include:

- Identifications of current conventional brickwork
- Process modelling for both ‘as is’ and re-engineered.
- Pre-assembly brick work process improvements
- Development of KPI (Key performance indicators) suited for brick-work construction processes.

RESEARCH METHODOLOGY

The research methodology of this research project was geared towards understanding current practices and in particular collating and analysing current and historical construction cases. More than 30 case studies were analysed and more than 100 interviews/observation were established. Industrial experts have contributed significantly to the development of this research through unlimited access to case studies and expert personnel.

More specific research methodologies are given below:

- A review of brickwork literature.
- Producing brickwork case studies.
- Company visits to investigate pre-assembled factory production in EU, and USA.
- A series of interviews focusing on brickwork business process standardization.
- A questionnaire aimed at pre-assembled brickwork producers in the EU and USA.
- Re-engineering strategy for process improvement.
- Measuring the KPI (Key Performance Indicators) for conventional brickwork.
- Modelling data to produce standardized business process options for conventional and pre-assembled masonry.

Three process levels of brickwork construction have been defined as the basis for evaluation of existing procedures, bench marking best practice and identification of process improvements. These are:

- High Level: Overall design and procurement
- Intermediate Level: Supply chain issues
- Basic Level: work-face operations (on-site or in a factory environment)
  Site/factory activities, construction techniques, transportation and erection.

The high level process is concerned with establishing clients needs and establishing approaches for fulfilling these needs through the use of standardized items (products) and processes. The intermediate level is concerned with the supply chain requirements and the ways in which to gear the supply chain in order to make the most of the high level process improvements. Finally, the basic level is about implementing standardized solutions. This tiered process approach will enable companies to develop their own re-engineering strategies to meet their particular information and physical brickwork process requirements. The paper focuses on the basic level process standardization and improvements.

CONVENTIONAL BRICKWORK FINDINGS

Over two dozen case observations have been used to identify problems associated with process and production control. Current practices suggest that bricklayers are working as they have been doing for hundreds of years. Innovation may come from within and simple procedure changes, such as the use of profiles and raised mortar-boards, can produce quality and output benefits. Experimental work carried out at Teesside University's structures laboratory, has proved that brickwork efficiency using the improved mortarboard approach.

The conventional UK independent tube and clip scaffolding system, highlights the current constraints associated with conventional methods of access. In mainland Europe and on the East Coast of America, the introduction of powered platform access is proving to be successful in rationalizing the conventional brickwork process. Powered access is flexible, contribute significantly to higher quality brickwork and assists in producing a higher standard of work and higher output.

The case studies indicate that ready mixed mortar deliveries systems are commonly used in the UK. Thus, alleviating the problems associated with conventional product inconsistency. European conventional brickwork improvements focus on removing all inconveniences around the craftsman, through the use of mortar silos and delivery of reduced pack sizes.

The following section introduces a mapping technique that has been adopted for measuring improvements in the process after incorporating the improvements methods. These methods are:

- Incorporating profiles.
- Incorporating raised mortarboards.
- Using powered access.
- Using Silo mortar

PROCESS MODELLING

An approach based on using a standard project planning system, Microsoft project, has been developed that can identify activity, duration and value, associated with conventional brickwork construction. The model presented in Figure 1 refers to a typical single square metre of brickwork in a housing situation based on the assumption of seventeen square metres of brickwork per thousand bricks. The flow of processes involved in building conventional brickwork is represented, including corners and details. By mapping current brickwork production sub activities using the live case studies, it was possible to identify the areas of value-added and non-value-added activities, see Figure 1. An example of the use of this technique for the identification of enablers at the basic level is presented. This determines what is achievable at the work face to reduce time, without compromising quality and covers the activity associated with support tasks. Figure 2 shows some of the possible re-engineered improvements to the conventional brickwork process. The original 72 minutes duration for setting corners using conventional mixing methods is shown in Figure 1. The re-engineered process reduces activity and incorporates silo mortar delivery, powered access work platforms and profile use in corner situations. The combination of these improvements to the process shown in Figure 2 reduces the overall activity duration down to 45 minutes. This illustrates how the method may be used to identify process improvements through a standardized approach to conventional brickwork activity. This can bring financial benefits in the form of shorter construction duration and earlier elemental completion (Fanning, Hobbs and Dawood 1999, 2000).

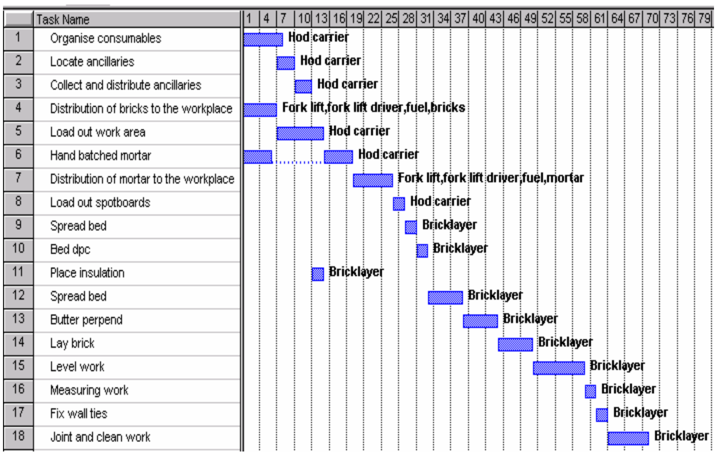

Figure 1: Conventional hand set processes

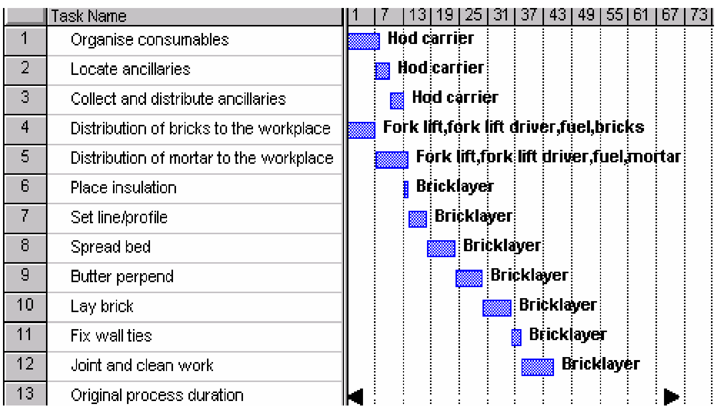

Figure 2: Incorporating Silo mortar, powered access and profiles

Figure 3 shows the saving in man-minutes over the construction of a typical m^2 of half- brick walling after adapting the proposed improvements (given in section 3) to the basic level conventional brickwork business process.

ID	Task	1 11 21 31 41 51 61 71 81 91 101 111 121 131
1	**Basic level potential process solutions for bwk**	
2	Mortar board	
3	C/w m2 conventional approach, duration mins	
4	C/w m2 conventional approach, duration inmins	
5	C/w m2, improved mortar boards duration mins	
6	KPI BENEFITS Nos. T2-T3-Q4-W1-W2-W3-E1 duration inmins	
7	Silo	
8	C/w m2 conventional approach, duration mins	
9	C/w m2 conventional approach, duration in mins	
10	C/w m2, site produced silo mortar duration mins	
11	KPI BENEFITS Nos. C3-T2-T3-Q2-Q3-W1-W2-W3-E1-E2-E3 duration mins	
12	Powered	
13	C/w m2 conventional approach, duration mins	
14	C/w m2 conventional approach, duration in mins	
15	C/w m2, s/m and powered access duration mins	
16	KPI BENEFITS Nos. C3-C4-T2-T3-Q1-Q2-Q3-Q4-W1-W2-W3-E1-E3 duration	
17	Profile	
18	C/w m2, 10 course conventional corner duration mins	
19	C/w m2, 10 conventional corner, duration in mins	
20	C/w m2, 20 course corner using profiles duration mins	
21	KPI BENEFITS Nos. C3-C4-T2-T3-Q1-Q2-Q3-Q4-W1-W2-W3-W4-E1 duration	
22	Profile	
23	C/w m2, Piers, arches and reveals m2 duration mins	
24	C/w m2, Piers, arches and reveals m2 duration in mins	
25	C/w m2, Piers, arches and reveals m2 using profiles mins	

Figure 3: Re-engineered conventional brickwork business processes (KPI: Key performance indicator given in table 2)

PRE-ASSEMBLED BRICKWORK FINDINGS

Pre-assembly brick-work is defined in this research as the process of laying bricks in a factory to form panels, piers, cladding, etc and then transporting these to construction sites. In this section, four systems/cases (from Europe and USA) are introduced and discussed and methods of improving business processes are also introduced. Case studies were identified, collated and analysed through the course of the research. Good practices have been highlighted and disseminated.

Anliker GmbH (Gremany). This is a factory based brick laying system comprising of CAD/CAM 'Wandplan' design platform, and an electrically powered walling machine (Multistone 800) capable of producing masonry at the rate of 30-40m^2 per hour.

Walling panels are produced in factory conditions with 300mm wide clay blocks. Planning, production and erection are all carried out in-house. Simple standardized details are arranged in various forms to create a range of dwelling options.

Sterk Bouw (Holland). This system is based on producing full-brick sandwich panels. Site construction processes are being rationalized by moving operations into the factory environment. Working from the early initial architectural instruction, production is scheduled to correspond with on-site activities. Improved working conditions combined with a "tilt-up full brick sandwich wall panel system" approach should reduce construction processes and provide high quality products.

Vet-O-Vitz Inc (USA). This is pre-assembled 'strongback' cladding masonry panels for a wide range of buildings. Panelization works due to the flexibility associated with off-site construction, superior quality control and the financial savings to the owner/client . These process savings can be quantified into:-

- Architects produce unique detailing on projects at a reduced cost.
- A substantial reduction in construction time.
- Pre-assembly provides solutions that would be almost impossible “in the field."

Inland Revenue Project (UK). This is an example of a project based standardization, 1032 manually laid brick piers pre-constructed in a in factory (see figure 21) produced a high quality and in-time products to a critical short construction period. The standardization approach (processes and products) contributing to delivering the required product consistency in relation to the critical dimensional tolerance and time constraints.

From the above, it can be concluded that pre-assembly approaches can deliver a high quality product and contribute to improving site construction processes.

Table 1 shows a proposed pre-assembly brickwork standardized process for the three levels; high, intermediate and basic. This has been developed from analysis of previous case studies and interviews with project managers and construction industry business process experts. Detailed information about the research methodology is not presented in this paper and can be found in A. Fanning, 2000.

PROPOSALS FOR KEY PERFORMANCE INDICATORS TO MEASURE PROCESSES

In order to measure the improvements in the processes proposed in this paper (for both conventional and pre-assembly brickwork), a number of key performance indicators have been developed from pervious literature to suite brickwork construction. Table 2 shows the Key Performance Indicators (KPI) which are grouped under the several drivers and Table 3 shows the proposed benefits and improvements.

CONCLUSIONS

The findings to date highlight a range of potential process improvements for on-site conventional construction and pre-assembled brickwork. The standardization of procedures incorporating such improvements has the potential to increase the efficiency of brickwork processes. Conventional masonry has a lot to offer the developer. The combination of detailed facades and rationalized process techniques at the basic level can deliver high quality and production rate at optimum cost. The pre-assembly case studies have shown how this approach can yield considerable benefits in appropriate circumstances. Standardized masonry processes can meet a number of Key Performance Indicator criteria. New approaches to using project-planning computer software provide a valuable business process re-engineering tool. Improved communication throughout the supply chain will also provide possible re-engineering enabling options at each level.

Finally, though no one single standardized solution may be applicable to all current instances and market sectors, a range of options to improve the current process, address productivity, quality consistency and waste reduction are achievable.

Table 1: Standardization of pre-assembled brickwork processes

	Process Improvement Criteria	METHODOLOGY	ACTION	Key Performance Indicators
High Level Information	▪ Understanding customers needs and supplying what they actually value. ▪ Design interaction producing environmentally sound, durable, buildable solutions before construction commences. ▪ Early involvement of all project members.	▪ Value engineering approach to cost reduction. ▪ Specialist contractors compatibility measured along with cost performance. ▪ Suppliers providing value through technical product performance and cost from outset.	▪ Negotiation approach to cost planning. ▪ Clear driven standardized approaches to concept design-live project execution and delivery of components and elements. ▪ A greater understanding of project risks, associated wastage and value streamlining.	**COST AND VALUE DRIVEN**
Intermediate Level Information	▪ Design professionals utilizing the available suppliers' technical input from concept through to project completion. ▪ Main contractors ' teaming' approach to product scheduling. ▪ Suppliers ensuring consistency and product certainty.	▪ Long term based business teaming with producers. ▪ Specialist contractors working closely with suppliers in order to reduce waste and add value to the process. ▪ Producing products that rationalize the process and shrink the system.	▪ Introducing Just-in-time process supply. ▪ Extending the definition of process value from suppliers through to producers. ▪ Benchmarking and measuring end users operations.	**COST, VALUE, PRODUCTION AND CULTURE DRIVEN**
Basic level Information	▪ Design professionals co-ordinated team approach to rationalizing buildability procedure. ▪ Main contractors 'driving the teaming' approach to production. ▪ Specialist contractors working to certainty regarding production value, quality and element delivery.	▪ Smoothing the transition to manufacture from craft without compromising the finished product. ▪ Culture development and driven skill rejuvenation. ▪ Ownership and workmanship responsibility.	▪ Delivering complete components efficiently reducing resource waste. ▪ Enhancing the ability to produce intricate details cost effectively. ▪ Utilizing a multi-skilled workforce.	**COST, VALUE, PRODUCTION AND CULTURE DRIVEN**

Table 2: KPIs which have been identified to measure improvements and standardized brickwork construction processes

PROCESS COSTS	PROCESS TIME	QUALITY	WORKING CONDITIONS	ENVIRONMENTAL ISSUES	CLIENTS NEEDS
C1 Cost predictability	**T1** Predictability of time	**Q1** Improved tolerance levels	**W1** Improved health and safety	**E1** Reduced waste of construction materials	**CN1** Client satisfaction of product
C2 Construction cost	**T2** Construction time of build	**Q2** Improved quality in appearance	**W2** Improved working conditions	**E2** Reduced waste of construction packaging	**CN2** Client satisfaction of service
C3 Reduced total process cost	**T3** Reduced overall project time	**Q3** Increased predictability	**W3** Increased productivity	**E3** Reduced waste of construction equipment	
C4 Increased profitability		**Q4** Improved performance			

Table 3: Proposed benefits and improvements

	Processes cost				Process time			Quality				Working conditions			Environmental issues		
Workface benefits																	
Jig profiles all market sectors	C1	C2				T2		Q1	Q2	Q3	Q4	W1	W2	W3	E1		
Corner and opening profiles all market sectors	C1	C2				T2		Q1	Q2	Q3	Q4	W1	W2	W3	E1		
Raised mortar boards all market sectors	C1	C2				T2		Q1	Q2	Q3	Q4	W1	W2	W3	E1		
Access options																	
Tower crane for commercial work				C4	T1												E3
Mobile crane all market sectors				C4	T1												E3
Powered access all market sectors				C4				Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Kwik form staging all market sectors																	E3
Mortar systems																	
Off-site rapid hardening mortar								Q1	Q2	Q3	Q4		W2	W3	E1	E2	E3
Off-site pressure fed mortar								Q1	Q2	Q3	Q4		W2	W3	E1	E2	E3
On site silo mortar								Q1	Q2	Q3	Q4		W2	W3	E1	E2	E3
Ready mixed delivered mortar								Q1	Q2	Q3	Q4		W2	W3	E1	E2	E3
Brick delivery																	
Improved packaging to all market sectors								Q1	Q2	Q3	Q4				E1	E2	E3
Improved pallet approach to all market sectors								Q1	Q2	Q3	Q4				E1	E2	E3
Reduced batch size to all market sectors								Q1	Q2	Q3	Q4				E1	E2	E3
Single firing delivery to all market sectors								Q1	Q2	Q3	Q4				E1	E2	E3
Conventional delivery to all market sectors								Q1	Q2	Q3	Q4				E1	E2	E3
Partial pre-assembly																	
Opening details to all market sectors	C1		C3		T1		T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Parapet details to all market sectors	C1		C3		T1		T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Corbel details to all market sectors	C1		C3		T1		T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Arch details to all market sectors	C1		C3		T1		T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Full pre-assembly																	
Conventional brickwork constructed strongback panels For commercial work	C1	C2	C3	C4	T1	T2	T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
Conventional brickwork constructed load bearing piers For commercial work	C1	C2	C3	C4	T1	T2	T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
RC cladding panels for commercial work	C1	C2	C3	C4	T1	T2	T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3
RC sandwich panels for housing	C1	C2	C3	C4	T1	T2	T3	Q1	Q2	Q3	Q4	W1	W2	W3	E1	E2	E3

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