

# IMPLICATIONS OF TECHNOLOGY TRANSFER IN THE DESIGN AND CONSTRUCTION OF LOAD-BEARING MASONRY BUILDINGS

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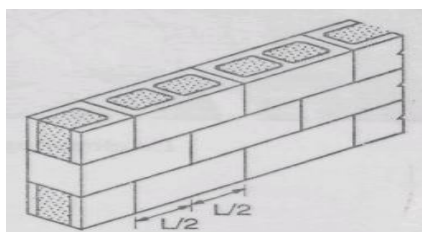
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## Graphical abstract



## Abstract

Load-bearing or structural masonry is a method of construction where the elements of a structure are built using masonry (bricks or blocks). Due to its technological and economic advantages, in western countries the system is widely used particularly for residential and low-rise buildings. Despite the advantages and excellent track record overseas, the system has not found its avenue in the local construction scene. Not many new buildings have been built using the system. Previous studies revealed that engineers, architects, developers, and builders lacked knowledge and experience on the design and construction using the system. A programme has been formulated for a consulting firm's staff and their business partners to transfer the state-of-the-art knowledge on the design, detailing, costing, and construction of structures using load-bearing masonry. Additionally, value added topics on supply chain, value engineering, and strategic planning were also included. The programme involved two phases: (i) a series of seminars and workshops covering a duration of 6 months and, (ii) continuous site supervision (monitoring) for another 6 months. An auditing scheme to measure the company's performance before and after the programme using the balance score-card technique is under formulation. The technology transfer programme has been completed covering 9 modules whereby the company managed to save further on profits by utilising value engineering concepts in its relevant projects.

**Keywords:** Masonry, load-bearing, building construction, value engineering, knowledge transfer programme.

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## 1.0 INTRODUCTION

Load-bearing or structural masonry is a method of construction where the elements of a structure are built using masonry. For the load-bearing wall system, the masonry walls are used to support building loads imposed by the roof, upper walls, and floor slabs as well as lateral loads such as wind and soil pressure. Due to its technological and economic advantages, in western countries the system is widely used. The

construction of residential buildings is mostly from unframed load-bearing brickwork or blockwork. It has long been used for earth retaining structures and bridges and it has also found new applications in the construction of larger span buildings such as those for sport, education, manufacturing and storage. Load-bearing masonry is not a new construction method. It has been used by mankind since the beginning of civilisation mostly using adobe and cut stones. The early construction was basically based on

rules-of-thumb, as such the structures were found to be bulky and massive. With the development of new materials, design philosophy and theories, which in turn led to the development new standards and codes of practice, today's masonry structures are taller, longer, thinner, and more slender as compared to concrete and steel structures.

## 2.0 LOAD-BEARING MASONRY CONSTRUCTION

Basically, there are three structural systems in building construction; the frame system, the flat slab system, and the load-bearing (or shear wall) system. A building can be built from either one of the systems or a combination of all. For the frame system, beams and columns are used to support the building loads and provide the necessary stability to the building (Figure 1a). Masonry merely acts as in-fills, i.e., partitions or walls that do not carry any structural loads. In this country, most of the buildings are from reinforced concrete frames and very few buildings use steel frames. For residential buildings, the former frame is more preferable. Bricks are sometimes used for columns. For the load-bearing or shear wall systems, the building loads are carried by the walls, in other words, there is no column (Figure 1b). The walls therefore provide a dual function; apart from acting as partitions, they also act as structural elements in providing support and stability to the building. Conventional load-bearing walls are constructed using mainly masonry or reinforced concrete (RC). RC load-bearing walls, technically called shear walls are used for core walls and lift shafts in high-rise buildings. For residential or other low rise buildings RC walls are normally pre-casted and then fabricated on site—also popularly known as prefabricated buildings. In the flat slab system, the slab sits on a column and there is no beam. To avoid 'punching' failure, the slab within the vicinity of the column is normally 'thickened'.

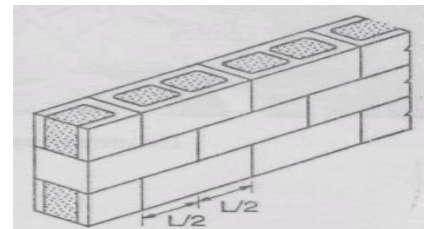


Figure 1 Building structural systems

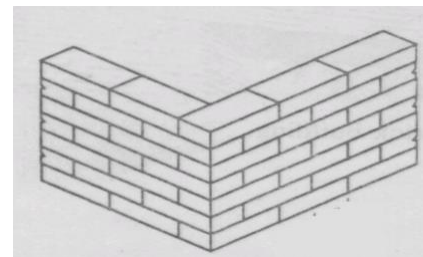
There are generally 3 types of structural masonry construction, namely; plain, reinforced, and pre-stressed masonry [9].

### 2.1 Plain Masonry

Plain or unreinforced masonry is the simplest to construct, as they contain no steel reinforcements (Figure 2). They rely on the strength of the masonry alone to bear the building loads. Because masonry is strong in compression but weak in tension, the unreinforced masonry is normally designed to zero tensile stress. This load-bearing construction is commonly used in low and medium-rise buildings in areas of low seismic activity. For spanning structures such as bridges and door openings, the tensile and bending stresses are eliminated by shaping the beams or walls to the form of arches.



(a) Plain blockwork (grouted)



(b) Plain brickwork (single-leaf)

Figure 2 Examples of plain masonry construction

### 2.2 Reinforced Masonry

As for concrete, steel reinforcement is added to masonry to provide the tensile and bending strength and improves the compressive strength (Figure 3). This enables the construction of a more slender column and wall, which in turn, allow higher and more slender load-bearing masonry buildings. In addition, building elements such as beams and stairs can be built using masonry that was virtually impossible before this. This construction is more preferred than plain masonry in earthquake prone areas. For reinforced brickwork, steel reinforcements are normally sandwiched or encased between two layers of units and bonded compositely using grout. For blockwork, the reinforcements are mainly laid inside the cores that are then filled with grout.

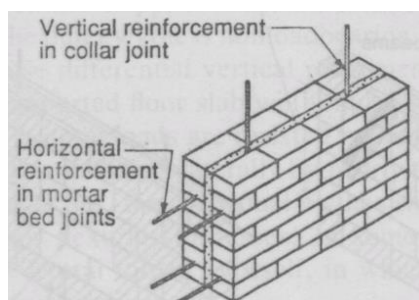


Figure 3 Typical layout of reinforced masonry construction

### 2.3 Pre-Stressed Masonry

The early form of pre-stressing was by placing a heavy statue on top of a column to increase its resistance to lateral thrust. Today pre-stressing is carried out by tensioning high strength steel rods or tendons embedded within the masonry structure (Figure 4). Steel rods or tendons are inserted at appropriate locations in an unreinforced masonry element and then tightened down against end plates so as to compress the element. In almost all masonry applications, the steel is centrally located in the element so the induced compressive stresses are uniform over its cross-section. The advantage of pre-stressing is that any subsequent tensile stresses that tend to develop are suppressed by the pre-compression. Pre-stressed masonry elements are designed to be free of tension under service loads. If minor cracks do occur under load, the pre-stressed steel closes them again when the load is removed. Other advantages are that pre-stressing rods can be inserted before or after construction of the masonry and they do not need to be grouted, provided that they and the anchorage are protected against corrosion. Pre-stressing allows much slender walls, columns, and beams to be built using masonry because it improves the load-bearing capacity as well as providing good resistance to dynamic response compared to the normal reinforced masonry. Typical applications are in the construction of diaphragm walls for sports complexes and earth and water retaining structures.



a) Post-tensioned masonry diaphragm walls

Figure 4 Examples of pre-stressed masonry construction

### 3.0 ADVANTAGES OF LOAD-BEARING MASONRY SYSTEM

Load-bearing masonry wall system offers several advantages when compared to the conventional reinforced concrete frame system. The overall construction cost is much cheaper mainly due to the elimination of cost of formwork for columns and beams as well as from the savings for using raft foundation instead of piled foundations. Both local and overseas experiences show that load-bearing brick wall system can be 10-20% cheaper than reinforced concrete building [17]. Haseltine and Thomas emphatically agreed that even for buildings more than four storeys, the system is more economical than many other systems [10]. In addition, the cost can be as much as 20% cheaper when using blocks instead of bricks [1],[ 3]. In terms of construction time, the load-bearing system has proven to be 30-50% faster compared to RC construction (ZNA, 1993). This can be achieved by eliminating or minimising the concrete formwork, very quick start-up of wall construction, and continuous construction due to the rapid strength gained from the brickwork. For reinforced concrete buildings, the proceeding construction has to wait until the casted concrete gains enough strength before the formwork and falsework can be dismantled. In terms of quality control, brickwork only needs visual inspection rather than site cube and slump tests as for concrete, since the quality of bricks are pre-tested at the factory during production [22]. In terms of durability, plain masonry structure does not pose any problem if used for coastal and marine structures as there is minimal steel reinforcement used. Brick walls has the longest estimated life cycle of 100 years compared to walls from concrete blocks (50 years), fibre cement (50 years), and vinyl (50 years) [8].

When compared to other building systems such as the prefabricated pre-cast building system which require economies of scale, load-bearing brickwork can be built even for one single unit at any location, may it be the urban or isolated rural area. It has the flexibility of construction to any layout required. Furthermore, the construction site using this system looks less messy than the reinforced concrete construction site. For high class or prestigious buildings, the cost of brick building can be higher than that of the reinforced concrete buildings. However, the former system is well known for its superiority in terms of aesthetic and cost of maintenance [13],[11]. The appearance of brickwork does not deteriorate with age.

Blockwork has many advantages compared to large structural panels used in industrial building systems. Construction using blockwork can be 30% faster than with brickworks [12]. They are small enough for mass production by fully automated mechanical processes, thus reducing labour costs. Transport and handling is simple and their cost is low; on site, the blocks can be erected without the necessity or the

use of cranes that is essential in large panel construction. In design, a high degree of flexibility is possible.

Apart from construction cost and time savings, the main advantage of blockwork is its 'buildability' over framed structures [18]. The advance in concrete technology has made modern structural blockwork an eminently strong and durable material. The use of mineral pozzalonas and chemical admixtures with high-tech casting and curing methods resulted in improved sound and thermal insulation as well as having fire resistant properties. Their ability to arch and span over collapsed sections tend to improve their robustness. It should be pointed out that with blockwork, a building can be design as a framed structure by reinforcing at locations such as beams and columns, similar to that in reinforced concrete buildings.

#### 4.0 ENERGY CONSERVATION IN LB MASONRY BUILDINGS

Reducing the energy consumption of buildings has become increasingly pertinent imperative because of the combined demands of energy security, rising energy costs, and the need to reduce the environmental damage of energy consumption. Exterior insulation provides the highest level of durability, energy efficiency, and comfort with the least technical risk. Specifically, externally applied insulation and air/water control layers have the following advantages: the insulation and air/water control layers can easily be made continuous and thus protect the existing structure (masonry) from rain, condensation, and temperature swings; thermal bridging at floors and partitions is eliminated; thermal mass benefits are enhanced; and access to conduct the work is often easier. However, despite the advantages of exterior insulation, many buildings must be insulated on the interior, for reasons such as aesthetics or zoning, and space restrictions. Interior insulation of load-bearing masonry is often desired to preserve the exterior appearance. There are many possible interior insulation approaches that are, by and large, reasonably well understood [23].

Rock or stone wool provides excellent insulating solutions in the load-bearing masonry buildings. Besides rock wool cavity wall batts for new construction, brick effect or pebble-dash finish insulation solutions are also available for exterior load-bearing masonry walls. Rockwool cavity wall batt is a resin-bonded rock wool insulating material in slab form for use in masonry cavity walls. The product is for use as fully filled insulation slabs to reduce the thermal transmittance of cavity walls with masonry inner and outer leaves in buildings of up to 25 metres in height. Besides rock wool insulation's thermal performance, the product is also very stable, durable, fire resistant, and inhibits rain penetration.

#### 5.0 ACCEPTANCE ON LOAD-BEARING MASONRY

To construct houses cheaper and faster to meet the growing demand for them and to provide affordable housing for the lower income group has always been the country's most important agenda. In the same instance, land and building materials are becoming more expensive and quite often the building industry faces shortage of construction materials. In addition, the country is also facing a shortage of workers in this labour intensive industry. In housing, using the load-bearing wall system can provide a good alternative. As most residential buildings in the developed countries are using this system and in many under-developed countries load-bearing brick houses are still being built from the low quality adobe and mud-straw bricks without facing many problems, using the system in this country should not pose any problems. Our bricks and blocks are comparable with the quality of bricks of the developed countries and are very much superior to those used in the less developed countries.

Despite the excellent track record (both locally and overseas), the combination of advantages offered by load-bearing masonry construction, gazetted under the Uniform Building By-Laws and had also won the prestigious Prime Minister's Award in the Low Cost House National Competition in 1995, the system has not found its avenue in the local construction scene. The adoption of the technology is still very low although the awareness of the technology is high. It is estimated that less than 1 per cent (both in terms of number and cost) of buildings built in this country used load-bearing masonry. A study was carried out to ascertain the reasons for the poor reception of the system amongst the industry players, namely the designers (architectural and engineering firms) and the builders (developers and contractors). Out of 124 companies surveyed, 90.5 per cent knew what the system was about while the remainder had no knowledge at all. Only 26.3 per cent of the responding firms with the knowledge had actually been involved in load-bearing related projects, while 83.7 per cent never had. The size of projects for those who had been involved is very small and limited to private bungalow units and small housing projects that cost in the range of RM50,000 to RM 2.5 million. About 10 per cent of them were involved in projects that cost more than RM10 million [2].

Table 1 gives the descriptive statistics of the perception on load-bearing system by the non-users. The most dominant reason for LB system not being widely used was that most industry players were more familiar and complacent with the conventional reinforced concrete techniques. They felt that this technique is sufficient in meeting the demands of their business undertakings. This is due to the fact that, most of them were mainly being trained and exposed to the reinforced concrete construction techniques—the technology that not only

dominated the local construction industry, but also the world. They thought that load-bearing construction would require special skills which our workers are lacking. The belief that the load-bearing buildings is difficult to renovate was still salient amongst those who had never used the system. In seminars and workshops conducted on load-bearing construction, this was the most frequent question posed by participants. Again this issue relates to the level of knowledge on the subject, where in fact, as for any other construction technique, the load-bearing buildings can undergo renovation but through proper design and planning.

Since not many of the industry players have had the experience of working with the system, they are unsure of the approval procedures and by-laws regarding the load-bearing system, where in fact, the system has been recognised and stipulated in the Uniform Building By-Laws 1984.

Above all these, there is no demand for the system as many felt that the reinforced concrete system is much better than the load-bearing system in many aspects. They acknowledged that they lacked proper knowledge on the design and construction of the load-bearing construction system.

It was found that not a single university in the country has given emphasis on teaching the load-bearing masonry design subject in their undergraduate civil engineering programmes. Those universities that taught the subject only allocated a few hours which were not comparable to the time allocated for reinforced concrete and steel design subjects.

**Table 1** Perceptions towards LB System by the non-users

Ranking	Items	Mean Score *
1	RC system is sufficient	3.86
2	No demand by the clients	3.82
3	RC building is easier to build and maintain	3.77
4	LB building is difficult to renovate	3.77
5	Lack of skilled worker	3.56
6	Lack of knowledge on the design	3.43
7	Lack of experience on the system	3.33
8	Not encouraged by others	3.45
9	Local bricks are of low quality	3.43
10	RC construction technologically is better than LB	3.30
11	Difficult to get approval	2.86
12	No confidence in LB system	2.48

\* Likert scale of 1 (strongly disagree) to 5 (strongly agree)

However, those who had used the load-bearing system gave a more positive response (see Table 2). It was obvious that industry players were expecting that more effort should be made to promote the use of the system.

**Table 2** Opinions on LBM by those who have used the system

Ranking	Items	Mean Score*
1	LBM needs promotion	4.33
2	LBM building is more beautiful than RC	3.53
3	LBM technique is faster than RC	3.43
4	Will use LB in future projects	3.30
5	Will recommend LB to others	3.27
6	LBM technique is cheaper than RC	3.20
7	LBM is suitable for Malaysia	3.13
8	Malaysian bricks are low quality	2.80
9	LBM technique is better than RC	2.73

\* Likert scale of 1 (strongly disagree) to 5 (strongly agree)

The majority of load-bearing users acknowledged that the technique was cheaper, faster, and looks more beautiful than reinforced concrete. It is interesting to note that the misconception regarding local bricks being of low quality and not suitable for load-bearing use was only prevalent within the non-load-bearing users, but not within those who have used the system. The non-users, who are lacking in experience on the system, seemed to have little knowledge about the materials. Our bricks, in fact, are of high quality and are as good as those used in the western countries. The British Standard stipulated that brick for load-bearing masonry should have a minimum strength of 5.2 N/mm<sup>2</sup> and most of our bricks complied with this requirement.

Load-bearing masonry was also not that popular for new buildings in other developing countries. For example, in the United Arab Emirates where 74 per cent and 84 per cent of the builders prefer reinforced concrete frame structure more than load-bearing structure for residential bungalows and low-rise apartments, respectively [16]. The majority of designers in those countries chose the framed structure believing it to be more advantageous in most aspects apart from economy and speed. The reasons given by those who chose load-bearing were not unanimous, except that they felt that the system was not popular with their clients. The behavioural reasons that builders prefer reinforced concrete over load-bearing system are rooted in the convention of 'over-design' in reinforced concrete structures, a lack of technical knowledge on load-bearing, unexplained bias, or are prejudiced against change, and the unexplained insistence on the part of client.

## 6.0 THE LOAD-BEARING KNOWLEDGE TRANSFER PROGRAMME

The goal of this work was to transfer knowledge on the design, detailing, costing, and construction of structures using load-bearing masonry, and to enhance the knowledge and practice using this system in the Malaysian construction industry.

## 7.0 PERFORMANCE MEASUREMENT WITH BALANCE SCORECARD

[4],[6] introduced the Balanced-Score Card (BSC) concept, which was a new performance measurement, back then, using four perspectives, namely financial, customer, internal business processes, and learning and growth. Though the BSC concepts are now being presented as part of a broader strategy execution framework [14], performance measures still form a central role of linking business analytics and operational scorecards to the BSC [14]. Different modified versions of BSC are still relevant and in use today; in fact, the BSC concept is the most actively used worldwide and is frequently applied as a powerful communication tool for performance measurement [15]. The purpose of BSC is defined as a management framework that translates an organisation's mission and strategy into a comprehensive set of performance measures that provide the framework for a strategic measurement and management system [7]. The Harvard Business Review has identified the BSC as one of the most important management ideas in the past 75 years. Organisations need to develop a mission and a vision with an end state in mind (strategy); to have stakeholder's buy-in; to identify resources; to adopt a methodology including how data would be collected, measured, and analysed; and to develop an action plan including training, communicating, and monitoring mechanisms for sustaining BSC implementation [5].

## 8.0 DATA ANALYSIS AND DISCUSSIONS

As evidenced in the literature many researchers [19],[20],[21] showed that BSC use is limited amongst SMEs, including Malaysian SMEs due mainly to lack of awareness, limited human and financial resources, lack of supporting software, lack of strategies

resulting in short-term orientation, and no formalisation of the processes. In addition, non-availability of pertinent data restricts the use of advanced BSC applications for performance measurement, and ZNA Consulting is no exception. Due to the economic crisis which happened in 2008, the majority of contractors earning per share had fallen from 2007 levels by around 80-95 per cent. SME contractors suffered a significant drop in their share prices of about 100 per cent over their 2008 level and received negative returns in 2009. As a result, since then, performance from the financial perspective is recognised as being the most important criterion for survival. The data obtained from ZNA Consulting, primarily, pertains to the revenues, gross profit, and expenses for three years; 2011, 2012, and 2013 as shown in Table 3 below. Comparative figures indicate that ZNA Consulting, despite industry hardships, benefitted from the Knowledge Transfer Programme. Figures from Table 3 are analysed below. There was an increase in revenue in 2013. Consultation revenues in 2013 were RM 4,524,890 compared to RM 4,377,031 in 2011 and RM 4,321,767 in 2012, which is a revenue increase of 3.4 per cent & 4.7 per cent over 2011 and 2012, respectively. There was also a decrease in cost of sales in 2013. The Consulting firm's costs of sales in 2013 were RM (1,710,408) compared to RM (1,754,328) in 2011 and RM (1,975,815) in 2012. Lower cost of sales was 37.8 per cent of revenue in 2013 compared to 40.1 per cent and 45.7 per cent of revenue in 2011 and 2012, respectively. This decrease in cost of sales may well be attributed to the company management applying the newly administered techniques for better utilisation of resources.

There was a modest decrease in administrative expenses in 2013. Administrative expenses in 2013 were RM (1,710,408) compared to RM (1,807,464) in 2011 and RM (1,812,507) in 2012. Lower administrative expenses were 37.8 per cent of revenues in 2013 compared to 41.3 per cent and 41.9 per cent in 2011 and 2012 respectively—indicating better understanding of managing admin expenses by the company. There was a significant decrease in other operating expenses in 2013. Other operating expenses in 2013 were RM (520,362) compared to RM (779,919) in 2011 and RM (572,602) in 2012. Lower other operating expenses in 2013 were equivalent to 11.5 per cent of revenue in 2013, as compared to 17.8 per cent and 13.2 per cent in 2011 and 2012, respectively.

**Table 3** Showing revenue, gross profit, and expenses for 2011, 2012, and 2013

REPORTS AND FINANCIALS STATEMENTS FOR THE FINANCIAL YEARS ENDING 31 DECEMBER OF EACH YEAR (FIGURES IN RM)					
#	ACCOUNT HEADING	2011	2012	2013	COMMENTS
1	REVENUE	4,377,031	4,321,767	4,524,890	Increase in revenue in 2013; 3.4% & 4.7% increase in 2013 revenue over 2011 and 2012 respectively
2	COST OF SALES	(1,754,328)	(1,975,815)	(1,710,408)	Lower cost of sales in 2013 comparatively; 37.8% of revenue in 2013 compared to 40.1% & 45.7% of revenue in 2011 and 2012 respectively
3	GROSS PROFIT	2,622,703	2,345,952	2,719,458	Increased gross profit in 2013 to 60.1% of revenues compared to 59.9% & 54.3% in 2011 and 2012 respectively
4	ADMINISTRATIVE EXPENSES	(1,807,464)	(1,812,507)	(1,710,408)	Lower administrative expenses in 2013; 37.8% of revenues in 2013 compared to 41.3% & 41.9% in 2011 and 2012 respectively
5	OTHER OPERATING EXPENSES	(779,919)	(572,602)	(520,362)	Lower other operating expenses in 2013; 11.5% of revenue in 2013 compared to 17.8% & 13.2% in 2011 and 2012 respectively

## 9.0 CONCLUSIONS

The dominance of the long rooted reinforced concrete system within the construction industry has made it difficult for the load-bearing system to penetrate into the local construction industry. Factors that caused the poor adoption of load-bearing system are mainly due to the reasons related to lack of knowledge and experience on the system. In fact, none of the local universities has really put emphasis on the teaching of this subject in their curriculum. This is rather unfortunate knowing that several prominent universities have put a lot of time and money embarking on extensive research on masonry materials and construction, and yet no specific subject on the design and construction of masonry structures has been offered in their civil engineering and architectural courses. At the skill training centres, although brick-laying courses are conducted, they do not cover much on load-bearing masonry construction techniques.

Reduction of waste materials is a great potential in brick and block making. Though technically viable, their performances so far have not been convincing enough compared to the traditional clay brick and concrete block. The cost for their commercial production is still high. However, effort to look for alternative materials should be continuing as they may be useful during the crisis periods or for environmental reasons.

The modules provided fundamental knowledge on value engineering and management principles in construction project planning and execution;

knowledge transfer formulated for the consulting firm's staff and their business partners to transfer state-of-the-art knowledge on the design, detailing, costing, and construction of structures using load-bearing masonry. It helped the firm to improve their overall business performance and for them to avoid costly mistakes by gaining an insight into the success and failure factors of projects. The firm's management team learnt many practical tips on; supply chain, value engineering, and strategic planning, thus enabling them to improve project leadership and motivational skills, communication skills, and project performances. These skills helped the company in forecasting time and cost of project completion that translated into higher revenues, lower expenses, and higher gross profits in 2013.

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