ABSTRACT

Modern buildings are designed to enhance the match between environment, spaces and the people carrying out work, so that the well-being and the performance of the occupants are all in harmony. Buildings are systems that facilitate a healthy working environment within which workers productivity can be optimised in the buildings.

The building is also required to support business attainment. Failure of the building structure or infrastructure, or its services will generally result in reduced business performance. The cost of running a business far outweighs the construction, maintenance and building operations costs. The use of Integrated Logistic Support (ILS), as a management discipline, assures the requisite “building” availability is met. ILS provides the discipline and process for building availability attainment to be met. ILS offers potential for through life cost saving coupled with business efficiency.

At the University of Reading an integrated approach has been developed to assemble the multitude of aspects inherent in this field. The means records required and measured achievements for the benefit of both building owners and practitioners. This integrated approach is represented in a Through Life Environmental Business Model (TLEBM) format using the concept of Integrated Logistic Support (ILS). This approach supports the construction practitioners in delivering and maintaining a better performance based building throughout the life of the building.
1.0 INTRODUCTION

Changes in society and technology are shaping our future. Demographic changes in population size and life expectancy, globalisation, communications and global change are some of the challenges and opportunities facing the world. Buildings are designed, constructed, managed or refurbished by people for people to work and live in. Dealing with old buildings and designing new ones is about providing a supply to meet a demand. Buildings create environments within them consequences. The consumption of materials, energy and water besides the emissions to the atmosphere and the production of waste mean that every consideration has to be given to their efficiency and effectiveness of operation. Equally important is the fact that there is quite a substantial body of evidence emerging, clearly showing that physical environment can effect people's mood and work performance and hence work output (Clements-Croome, 2003).

The increasing age of buildings and building services systems has the potential to cause deterioration of operability and maintainability of the building as well as its services. This is mainly due to the fact that, major construction projects have traditionally been planned, designed, developed, built, and delivered to the customer or user with very little consideration given to the aspects of maintenance, operation and support (O'Dell, 1996; Jones, 1999). This practice has been expensive because the cost of maintenance, operation and support constitutes a major portion of whole life cost. Over the lifespan of many types of buildings an owner will meet maintenance and repair costs equalling two or three times their initial capital costs. Evans et al (1998) in a report entitled The Long-term Costs of Owning and Using Buildings for the Royal Academy of Engineering made a point that the cost of ownership and maintenance of the building is typically about 3% of the overall cost of people working there. As a guide to the whole life cost of operation of office buildings the following life cost ratios were proposed (1: 5 to 9: 200). Long-term changes in building demand will oblige the building professions to shift their focus to performance based buildings that meets the clients expectations especially those concerned with business functional requirements.

Performance Based Building aims at using performance requirements to define a building or building product’s fitness for purpose. Performance Based Building means the emphasis on the ends rather than means: it describes buildings and building products on the basis of the target performance rather than in terms of solutions and technical specifications. For performance based building focusing on the end-user requirements is the main challenge. It requires finding the language to express the quality of a building in terms understandable to the end user and to relate user requirements to building characteristics and performance.

This language can only be produced by multi-disciplinary scientific research and must be related back to professional experience and practice. Many of the methods from research are not fully developed and will have to be formalised by architects and engineers, who are familiar not only with the traditional skill and art of building, but also with the various scientific methods required by the construction practitioners and facilities manager. The multi disciplinary approach requires systems thinking to identify, assess the importance of these performance measures, and develop a consistent management of the data through the life cycle of the project. This paper deals with the systems approach and the merits of the performance based method.

2.0 THE SYSTEMS APPROACH IN SOLVING BUILDINGS PROBLEMS

Systems’ thinking is a holistic approach to problem solving and as such strive for comprehensiveness in analysis and application. Systems practitioners make decisions based on value judgements and limited information and data to work with. These include judgements about who to include in the analysis, how to conduct the investigation, how to critique the conclusions, where to synthesis ideas, and when to act. By recognising the inevitable incomprehensiveness of everything we do, and by designing methods that help us to be more effective about values, boundaries and interconnections, the ways in which we engage with others can be improved. Understanding systems behaviour is more important than trying to completely understand every element within the system.

Elements within the systems can be classified in a variety of ways. Some systems are relatively simple and characterised by having a small number of elements with few interactions between them e.g. doors). Such systems can be governed by well-defined laws of behaviour and do not pursue their own goals and have subsytems that are passive (e.g.
At the other end are those systems that are very complex and have a large number of elements, all of them highly interrelated and exhibiting non-linear dynamic behaviour (e.g. air condition).

A system in the building industry can mean anything from a process to a product; both include human beings. The design of performance-based building systems and its evaluation cannot be complete without engaging in the systems thinking approach where the value of the whole is greater than the sum of its parts. The design of the buildings is based on different sub-systems which combine to augment the effectiveness of the building (e.g. structures, services). A building system thinking approach includes the following characteristics: elements; interactions between elements, feedback control, structure, connectivity, together with purpose and goals as inputs and outputs of what is expected of the building.

The systems approach to the performance concept was developed, formalised and applied to the development of building performance specifications at the US National Bureau of Standards in the early 1970s. The systems approach to the performance concept was discussed in various publications, including proceeding of the CIB-ASTM-ISO-RILEM 3rd International Symposium “Applications of the Performance Concept in Building” (Tel Aviv, 1996); (Hattis & Becker, 1999).

3.0 THE BACKGROUND AND IMPORTANCE OF PERFORMANCE BASED BUILDINGS SYSTEMS

King Hammurabi of Babylonia reigned from 1955 BC to 1913 BC and has been credited with the first recorded building regulation. It was a performance statement and addressed only one aspect of user requirements of the house structural safety (Gross, 1996). About 350 years ago, Sir Henry Wooten observed that ‘In architecture as in all other operative arts, the end direct the operation. The end is to build well. Well building hath three conditions; Commodity, Firmness and Delight’. Commodity is just not the buildings’ ability to serve a useful purpose; but also the changing needs. A well structured building can be expected to last for well over seventy years during which time it will most likely have been through several changes of owner and a similar number of changes in utility. Thus adaptability and flexibility should be one of the cornerstones of the design and treated as such. Firmness is a measure of the soundness of a structure and its ability to stand the test of time. As time is a distinguishing feature here, we must combine initial robustness with a facility for sensible maintenance, repair and renovation. Delight will obviously depend upon the observer. Aesthetics should not be bypassed as they are usually a mirror to the times in which the structure was erected and as such will act as a cultural heritage.

The performance approach addresses the commodity, firmness and delight issues for good building practice and provides the foundations upon which building life cycle approach can be addressed. The performance approach is concerned with what a building is required to do, and not with prescribing how it is to be constructed (CIB 60). Performance is partly a subjective issue. As a precursor to addressing the performance of a building or structure, it is essential to define the functional requirements in terms of the total real-life experience which the building products may be subjected to. In the book titled ‘Standards in building’ Nagarajan (1976) argues for a structured approach to defining, designing and constructing buildings. By following a standard methodology for classifying the product at all elemental levels, he surmised that buildings could be more reliable and predictable. Rather than provide a specification which the contractor is to adhere closely to, it was suggested that a performance level or standard should be specified which would then give the manufacturer/contractor a degree of latitude in deciding what to provide and how to provide it. Performance standard based on functional requirements dictate all other design features, including the choice of materials. Performance standards enable the user to make a judicious choice between different products, taking into account economic and aesthetic considerations (Nagarajan, 1976). Every attempt should be made to make quality decisions on all aspects of the design, construction, operation, maintenance and final de-commissioning of the facility.

Achieving consistent, reliable productivity and performance of a company’s business begins for most companies with adequate built facilities to operate the business. Performance problems and failures of the facilities can quickly drive away today’s demanding customers. Likewise, stakeholders, investors and clients are increasingly unforgiving of poor
performance, both in the infrastructure and the technology. Poor performance or failures of the infrastructure may result in lost revenue, devalued stocks and a tarnished reputation, all of which can stifle growth and make the business of the company less competitive. Supporting a successful business through its built facilities means managing a continuous process of support of the operation and maintenance of the built facility. Once a performance based facility is constructed it needs to be operated, maintained, and supported throughout its design life. Therefore, a good quality building is needed. The major performance parameters related to user’s availability are shown in Table 1.

### TABLE 1.
Building System Performance Parameters

<table>
<thead>
<tr>
<th>Performance Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>Anticipated total system uptime</td>
</tr>
<tr>
<td>Conformance</td>
<td>Success in meeting design/client requirements</td>
</tr>
<tr>
<td>Durability</td>
<td>Usable Life</td>
</tr>
<tr>
<td>Expandability</td>
<td>Capacity for future growth</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Length of system downtime as measured by Mean Time to Repair (MTTR)</td>
</tr>
<tr>
<td>Reliability</td>
<td>Component quality over time as measured by Mean Time between Failure (MTBF) / Energy reduction / User productivity</td>
</tr>
<tr>
<td>Risk</td>
<td>Business impact from loss of load; cost of downtime</td>
</tr>
<tr>
<td>Simplicity</td>
<td>Ease of operation; elimination of human error</td>
</tr>
<tr>
<td>Quality</td>
<td>Fitness for Purpose</td>
</tr>
<tr>
<td>Value</td>
<td>Costs of improvement &amp; sustainability issues</td>
</tr>
</tbody>
</table>

#### 3.1 Basic Components and Structure of a Performance Based Building System

The current prescriptive (or specification) based building consists primarily of a collection of codes and standards that describe how buildings should be designed, built, protected and maintained with regard to the health, safety and amenity of the general public. An alternate framework for a performance-based system is one that has three separate components: codes, standards and evaluation & design tools. At a minimum, the code should explicitly state societal goals, functional objectives, performance requirements, and accepted methods be specified in a single document. By contrast, performance-based codes describe requirements for health and safety through a set of flexibly defined performance objectives and functional requirements (Hattis & Becker, 1999).

The various players in the design and construction processes can all have different views on what performance requirements are necessary for any particular building but ultimately it is the user that will judge the success of the building. This means that performance based building should aim to set criteria which are valid from conceptual to disposal stages. There is a fundamental difficulty in selecting certain criteria because there are objective and subjective factors. For such an approach to be effective it is necessary to have collaborative interdisciplinary teams working to ensure that no factors are omitted from consideration at the commencement of the project and the value and the mission are agreed by all participants at the outset. This means for example there will be planned maintenance and facilities management procedures in place; there will be continuing commissioning procedures so that performance is monitored when the building is in use. However, from recent workshops held for practitioners within the School of Construction Management and Engineering, at The University of Reading, the factors shown in Table 2 are prevalent in the current design of building within the industry. Ultimately the aims are to increase value to the client; decrease life cycle costs; reduce miscommunication throughout the building process. System availability is one measure which is used to evaluate the performance of a system.
TABLE 2.

Current Approaches to Design of Buildings

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Yes (Frequent)</th>
<th>No (Seldom)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity of design</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Risk assessment</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Cost (Capital)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Whole Life Cost (WLC)</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Space Availability</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Access Requirement</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Construction Time</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Sustainability</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Reliability (Availability)</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Maintainability</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Supportability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.0 TOWARDS A NEW FRAMEWORK FOR PERFORMANCE BASED BUILDINGS

In order to make strategic decisions about building facilities, it is essential to be able to assess their value to the business units. Lacking any systematic way of measuring functionality, most top executives and core business managers, have just tried to ratchet down occupancy costs for workplaces, rather than leveraging workplace costs by paying attention to the effectiveness of the occupants. Now, however, a standard methodology is proposed under the TLEBM method, whereby information can be stored and retrieved as well as analysed and evaluated for strategic decision-making both now and in the future. Good data translates into informed decision-making. Balancing facilities costs and their impact on staff retention, time to market and business competitiveness are currently important. In order to convince senior management that functionality and quality are important, it is essential to have a case well documented, and linked to business effectiveness. Such decisions will be invaluable in developing strategic polices about assets of renovated and new facilities.

4.1 The New Approach

Integrated Logistic Support (ILS) is a structured management approach aimed at influencing the design of a product and ensuring that all the elements of design are fully integrated to meet client’s requirements and the facility’s operational, maintenance, and safety needs at a minimum whole life cost (United States Department of Defence, 1983; United Kingdom Ministry of Defence, 1996). ILS was initially developed in the United States and defined in MIL-STD-1388. In the early 1990s it was introduced into the United Kingdom, being defined in DEF-STAN 00-60. The main objectives of ILS are to:

- Influence project design and the operational, and through life maintenance requirements;
- Integrate the ILS issues (i.e. reliability, maintainability, level of repair analysis and whole life costing, etc.);
- Achieve high operational availability (i.e. the practical availability of the system when support requirements & plans are in place) at lowest life cycle cost;
- Develop appropriate ILS tools;
- Perform design trade-offs to optimise operational, maintenance provisions and economic and environmental issues;
- Measure the impact of alternative design solutions on life cycle costs;
- Identify, develop and schedule the necessary resources provided.

As a consequence the adoption of ILS saves waste in terms of resources and staff time, hence money. ILS has been applied with considerable success in the ship design, automobile, aerospace, defence and nuclear industries and more recently in the housing sector. It is a highly structured management approach which utilises a proven suite of tools. These analytical tools address; availability, reliability, maintainability analysis, failure modes and effects analysis, reliability centred maintenance, training needs analysis, human factor analysis and whole life costing. All these aspects do not normally feature in the building design.

The Through Life Environmental Business Model (TLEBM) shown in Figure 1 is a framework representation of whole life performance and sustainable issues of a building, whereby the technological issues and economic issues about a building are investigated. TLEBM goes further in addressing the sustainable issues arising out of the development, construction, operation and maintenance of the building in a pragmatic way. Within this framework, the performance issues of function within the environmental, social and economic issues are addressed. Figure 1 shows the framework with the processes and sustainable issues. There are three parts to this model. The first is the connectivity of the supply chain processes and the interrelated working conditions and the relationships between the practitioners’ of the industry; the second addresses the whole life performance (functionality, performance, value) aspect that embraces the economic, social and environmental concerns within each phase of the building life cycle and the third is the value associated to the project on the minimisation of the impact of risk and the cost of the project.

The first part of the TLEBM was discussed in a paper presented at the CIBSE Conference Part 2 2002 (John et al., 2002). The procurement route and type of contract is paramount in the use of this methodology. The TLEBM model uses best practice techniques tailored from defence, aerospace industries to meet the needs of whole life performance using the tools and techniques of integrated logistic support. The ILS technique provides an integrated management approach to identify the optimum business solution to the problems of increasing costs in use which often result from operability, maintenance, and availability not being considered at the design stage. By systematically defining the building system, identifying its functions and describing the environment in which it exist, performance requirement are laid out.

Essentially the second part of TLEBM framework aims to co-ordinate and tailor the behaviour of the tools and techniques required in analysis of the system, as well as identify the ways in which a tool might be used, and at what stage in the life cycle process (e.g. design) it might be applied. Aguirre’s (1993) work is used together with Stephenson’s (1995) extension in the conceptual stage of the building system design. Aguirre identified three internal properties of technical systems, namely simplicity, clarity and unity. Stephenson developed Aguirre’s work by extending the link between internal properties of the technical system and the external properties of performance, economy and reliability of the technical system (Pahl & Beitz, 1996). Their method qualitative and is of particular use when used to compare different configurations. Furthermore the method facilitates the identification of ‘unreliable’ areas of design configuration which may cause reliability problems in the future. This stage of design is critically important as it is where many key issues, like durability, reliability and cost are fixed. FMEA (failure mode and effect analysis) and the other ILS tools are all essential in defining, designing and construction a performance-based building.

Although improvement at all stages in the life cycle process of the project is imperative, it is expedient that sustainable issues and other improvements be focused at the design and operation and maintenance stages where the life cycle cost are most significant. At the design stage the design specifications would have to be performance related rather than prescriptive as this would strip the design specifications of any possibilities to select preferred materials. The trade-off between competing designs attributes are therefore required to come up with an optimum cost solution as well as acceptable risk to the project.
5.0 THE BENEFITS
The long-term benefits to performance using the TLEBM methodology are:

- Improved supply chain management and reporting;
- Reduced wastage (i.e. time, people and money);
- Supported selection of responsible contractors and manufacturers;
- The adoption of environmental impact reporting;
- Development and acquisition of information required by the industry to enable informed decision-making;
- The adoption of environmental impact reporting;
- Supported selection of responsible contractors and manufacturers;
- The adoption of environmental impact reporting;
- Development and acquisition of information required by the industry to enable informed decision-making;
- The development of credible, robust whole-life assessment tools and guidelines on the subjects of design for flexibility, adaptability, recyclables and reuse;
- Progress and awareness evaluated and measurable targets developed;
- Reduced liability;
- Reduced operating costs;
- High quality, low risk selection of building materials and its services;
- Improved business performance for the organisation.

Much research has been aimed at understanding the patterns of energy consumption in occupied buildings and at reducing consumption. However, as the energy consumption of occupied buildings is reduced, insulation standards improved with more efficient plants and better controls, the other components in the life cycle become more significant. Therefore TLEBM holistic approach fosters more performance based building design, construction, operation & maintenance with better integration of social, environmental and economic factors.

6.0 DISCUSSION AND CONCLUSIONS
Performance-based building involves considering the entire life of buildings, taking environmental quality, functional quality and future values into account. Accordingly, policies that contribute to the whole life performance of building practices should be implemented, with recognition of the importance of existing market conditions. Both the environmental initiatives of the construction sector and the demands of users are key factors in the market. These are issues dealt with within the TLEBM model.

Buildings make high impacts on the environment in various ways. Construction projects typically consume large amounts of materials, produce tons of waste, and often involve weighing the preservation of buildings that have historical significance against the desire for the development of more modern designs. Similarly energy and water consumptions and waste outputs in buildings are high.

A key prerequisite in the implementation of Integrated Logistic Support (ILS) in building construction is the development of an effective, yet flexible, TLEBM to capture all the relevant data in a structured and normalised format. It is seen that ILS may be suitable for solving some of the problems in the building service sector of the construction industry, when fully developed within a TLEBM. It is envisaged that buildings designed within this framework will give a sustainable whole life performance.

Case studies are currently being evaluated to fully understand the methodology used and to further improve on the presented framework. The case studies involve new buildings as well as refurbishment ones. Preliminary findings show that the framework would evolve into a robust consistent data information source for the industry. The final outcomes of the case studies would be reported in future research papers.

This research project offers the opportunities to influence future building projects through the application on ILS disciplines which provide a holistic analysis of “through life” activities. The analysis and design of any building systems ideally should be aligned to whole life cost, covering all project phases from concept through to disposal.
8.0 REFERENCES


FIGURE 1.
Diagram of Through Life Environmental Business Model

Function
Performance
Values

Client Brief
1. HFA
2. Risk analysis
3. Environmental

Design
1. FMECA
2. LORA
3. RCM
4. WLC
5. Environmental

Installation/Construction/Commission
1. H & Safety
2. Environmental
3. FTA
4. Repair/Discard

Operation & Maintenance
1. RCM
2. Repair/Discard
3. Environmental
4. FMECA
5. TNA

Disposal/Reuse/orRecycle
1. H & Safety
2. Environmental

Key to Diagram
FMECA – Failure Mode Effect Critical Analysis
FTA – Fault Tree Analysis
HFA – Human Factors Analysis
H & Safety – Health & Safety
LORA – Level of Repair Analysis
RCM – Reliability Centred Maintenance
Repair/Discard – Repair and Discard Model
TNA – Training Needs Analysis
WLC – Whole Life Cost