A Review of Operability and Maintainability Strategies Adaptable To Energy Efficient and Low Carbon Buildings

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Abstract
It is widely believed that wide gap exists between designed and in-use performances of buildings, particularly buildings designed with energy efficiency or low carbon emission in focus. Clients/end-users of these buildings appears not to be getting long-term value for their investments due to the associated operation and maintenance challenges of the fitted unconventional systems. The issue of building operation and maintenance has being of growing concern and has thus led to the adoption of various procurement routes in the industry and other maintainability strategies. However, studies show that current procurement routes do not adequately ensure maintainability of buildings, mainly because maintainability was not considered at the design stage of the projects. Demand for energy efficient technologies and the growing awareness on issues of operability and maintainability in the industry, calls for attention from energy efficient building designers to show how these new and innovative technologies in low carbon buildings can be operated and maintained long into the future. This paper therefore reviews and analyses the concept of maintainability and operability, as well as some operability and maintainability strategies available in literature, to examine how they sit in within low-carbon buildings set-up.

Keywords: Design Process; Energy Efficient buildings; Operation and Maintenance; Prove Operability and Maintainability

1. INTRODUCTION

The development of buildings of varying typologies to meet current demands for sustainable solutions calls for good consideration to the maintenance of these buildings and the fitted technologies. It becomes more imperative when we realise that building elements, components and materials are not only exposed to the fast changing elements of the climate which cause wear and tear and ageing, but are also subject to man-made causes such as misuse or mishandling, accidents and even change of taste.

Many government reports on the construction industry such as the Latham (1994) and Egan (1998) have emphasised the need to improve construction. The reports identified poor co-ordination and communication, minimal research and development and lack of customer focus, among others as key inhibitors to the industry's performance (Cahill & Puybaraud, 2003; Murray, 2003). Recent researches have also shown that significant differences are often found between the design and measured performance of buildings (Birchall, 2011). Also, research on 2016 emissions targets for zero carbon homes suggests that action is needed by Government and industry to investigate and tackle the perceived gap between the calculated energy performance of new buildings at the design stage and the as built performance of same buildings (DCLG, 2012). Many factors could be responsible for this disparity, however, it had been argued that the information gap between the design team and the end users of the building is one (Malekzadeh, Bouchlaghem & Wheeler, 2011).

This paper therefore identified the need to integrate operability and maintainability into the design process of LCBs as one approach to bridging this performance gap and ensuring that the technologies are safely and efficiently operated and maintained long into the future. So the study focuses on the review of maintainability strategies available in literature; examining the barriers to their successful application with LCBs, and what best practice approach that could be adopted to ensure operability and maintainability. In this first part the authors examine basically the maintainability optimisation strategies available in literature; exploring their enablers and barriers as effective maintainability tools.

2. BACKGROUND LITERAURE

Sources from literature revealed that Building Care/Maintenance is an area that is not adequately researched (Lewis, Elmualim, & Riley, 2011; Wood, 2005). Wall (1993) posits that a search of published sources revealed a disappointingly small and fragmented literature relating mostly to technical and managerial aspects of building maintenance. Quah (1990) also noted that the growth and awareness of the importance of maintaining buildings has unfortunately not been matched with sufficient research and development. RICS (2000) argues that building maintenance has been the 'Cinderella' of the building industry for many years, with insignificant consideration given to innovation and 'free thinking' in the delivery of its services. RICS (2009) conveyed the same assertion.

2.1 The Concept of Maintainability

The term 'Maintainability' was pioneered by the United States Military service in 1954, (Blanchard and Lowery, 1969). The intent was to provide designers with a source of specialized skills and knowledge related to the support and maintenance of equipment and systems (Ibid). Maintainability is described by the US Institute of Technology and Science as; "*a characteristic of design and installation, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources*" (ITS, 1996). BusinessDictionary.com defines it as a *"Characteristic of design and installation* *which determines the probability that a failed equipment, machine, or system can be restored to its normal operable state within a given timeframe, using the prescribed practices and procedures"* (Businessdictionary.com, n.d.). Dunston and Williamson (1999) also defined maintainability to mean *"The design characteristic which incorporates function, accessibility, reliability, and ease of servicing and repair into all active and passive system components, that maximizes costs and benefits of expected life-cycle value of a facility".*

Dunston and Williamson related the definition more to buildings (facilities), with emphasis on maximizing costs and benefits of expected life-cycle value of the facility. Blanchard and Lowery (1969) makes it more explicit; *"Maintainability is a characteristic of equipment design and installation which is expressed in terms of ease and economy of maintenance, availability of the equipment, safety, and accuracy in the performance of maintenance actions."* Chew (2010) defines it as *"the ability to achieve the optimum performance throughout the lifespan of a facility within the minimum life cycle cost".*

In concluding, and deducing from the above definitions, maintainability is a design characteristic; qualifying a design with respect to ease, safety and cost that will be involved in maintaining the designed building, after it has been built. So, *'maintainability in building design'* would be said to mean 'a design that is conscious of the ease, safety and cost of maintenance, not compromising standards and quality, but ensures that building elements and components are kept in their continued good appearance and functional state, through the building life-cycle'. The outcome of maintainability will be a maintainable design; a maintenance conscious design.

2.2 The Concept of Operability

The word operability appears to be scarcely defined in literature, however, BS EN 61069 – 6: 1998 defines operability as "the extent to which the operating means provided by the system are efficient, intuitive, transparent and robust to accomplish the operator's tasks. Again, this definition is applied to Industrial-process measurement and control – Evaluation of system properties for the purpose of system assessment (BSI, 1998).

However, a review of the etymology of the word *'Operability'* shows that it is a noun form of the word *'Operable'*; derived in the 1640s from *operate* + *-able* (Harper, 2012; Dictionary.com, 2013), or derived from late Latin – *operabilis,* equivalent to *opera(ri);* meaning 'to work' + *-bilis* '-able'; that is; "capable of being put to use" (Ibid). Relating to building therefore means that an operable building is a building that is capable of being put to use or can be put to use with ease.

A document specifying 'operability, maintenance and construction' requirements for facilities output for the Priority School Building Project (PSBP) in discussing operability states thus; "*Buildings and grounds should be designed so that the facilities are straightforward and efficient to operate, with sufficient information provided to enable school staff to use facilities effectively. …"* (Department for Education, 2012).

From the foregoing, it seems proper to conclude that like maintainability, operability is a design quality that assures that the facilities are easy and efficient to operate. Following the BSI's application of the definition to Industrial process measurement and control – evaluation of system properties for the purpose of system assessment, operability of a design can also be viewed as a design process measurement and control factor used for evaluating the design for

the purpose of assessing the design quality. So, that measurement and control factor is 'operability'.
Design Operability as used in this thesis is a design quality measure that ensures that the facilities are operated in the most efficient, intuitive, transparent and robust way possible.

3. OPERABILITY AND MAINTAINABILITY OPTIMISATION STRATEGIES

There has been an increasing awareness of the concept of maintainability and operability of buildings; particularly with the deployment of new and innovative low carbon systems to replace the conventional fossil fuel driven systems in building. A number of strategies aimed at aiding efficient operation and maintenance of buildings have been proposed in literature. This section discusses these strategies; how they sit in the UK built environment industry and how they can be applied to operability and maintainability of LCBs design.

3.1 Procurement Strategy

Evidences in literature reveal that emphasis on private sector participation in public sector building delivery has become very popular among governments, as it combines the procurement of design, construction, operation and maintenance from a single source (Demirag, Khadaroo, Stapleton & Stevenson, 2012). According to Wood (2003b), it is hypothesized that this route of procurement will encourage the provision of more durable and long-life structures and components. The Public Finance Initiatives (PFI)'s primary objective is to transfer the responsibilities and associated risks of funding, designing, building, operating and maintaining public infrastructure to the private sector over a period of usually 25 to 30 years (Harris, 2004; Smith 2004 and Pretorius, Lejot, McInnis, Arner, & Hsu, 2008). In addition, the requirement for buildings to be maintained to high standards within the contract period was also expected (House of Commons, 2011).

In most other countries like China (Ho, 2006), Nigeria (Ibrahim, Price & Dainty, 2006), Singapore (Gunanwansa, 2010) and India (Research Republic, 2008), the PFI exists as Public Private Partnership (PPP) operating with the same principles. Many variants of private sector participation in public infrastructural delivery had existed before the advent of the PFI/PPP in these countries. Commonest among the lots is the Build, Operate and Transfer (BOT). In China for instance, BOT was introduced in the mid '80s (Cheng and Wang 2009) and early '70s in Honk Kong, with the building of the Cross Harbour Tunnel between Hong Kong Island and Kowloon in 1972 (Kumaraswamy and Zhang 2001).

The marked difference between these BOT variant and the PFI as it operates in the United Kingdom is that while in the BOT variants the investor recoups his investment from private patronage of the services, in the PFI, the investor is reimbursed by the public sector client annually, over an earlier agreed period, usually 25 – 30 years. A very unique advantage of these routes of procurement is that the operation and maintenance responsibilities of the facilities are vested on the contractor/investor who normally is expected to keep the facility in high maintenance standard (House of Commons, 2011).

The question here, to which no answer is found in literature is, '*what happens to the facility after it has been transferred to the public sector for management?'* Wood (2003b) reported that fears are already being expressed that a contractor may be tempted to hand-over a building in very poor condition of repair. There have also been many other concerns within parliament, researchers and the general public, suggesting that neither PFI/PPP nor BOT can ensure maintainability or sustainable maintenance practice. The PFI system has also been widely criticised as a back-door form of privatization, locking the public sector into long-term financial commitments and offering poor value for the taxpayer's money (Wilson, 2002). It is also believed that PFI arrangement has become far too expensive than expected, a means of transferring debts to future generation, mortgaging the nation's future and not providing good value for money (Smith, 2004; House of Commons, 2007; Monbiot, 2010; Norman, 2010). House of Commons (2011) noted that there was no clear and explicit justification and evaluation found for the use of PFI in terms of value for money. Also, in terms of maintenance, that the requirement for buildings being maintained to high standards over the life of the contract is supposed to be a key benefit of PFI, yet some hospital Trusts were not satisfied with the maintenance services".

However, it is clearly understood that even if the choice of a procurement route could ensure high standard of maintenance; it cannot guarantee maintainability, if maintainability factors were not factored into the design. It is commonly believed that since the investor/developer is responsible for maintenance, he will design buildings that are maintainable (in terms of cost, safety and ease). This may not always be the case, since the additional cost in the PFI is ultimately borne by the public sector client (Demirag et al, 2012). PFI investors and contractors are business organisations and will naturally seek to maximise profit at the expense of other considerations (HC. 68, 2010). Since the cost of O&M is built in from inception of project, the more capital assigned to it, the more profit margin they get.

There are other forms of contracts involving whole-life-costing (WLC); Prime Contracting and Partnering Arrangement. In these forms of contracting projects are procured from a single source, but unlike the PFI, O&M is procured separately. However, there is tendency for operability and maintainability to be factored into the design process, following the WLC approach. Details of the WLC approach are discussed in section 3.4.

There are also evidences showing that majority of clients in the UK prefer the traditional method where design, construction and O&M are procured traditionally. The Royal Institute of Chartered Surveyors (RICS) recently published in Langdon (2011) and Langdon (2012) the results of a survey of contracts in use in the UK undertaken within 2 – 3 years intervals from 1985 – 2010. The result shows that majority of building contracts in the UK were procured through various variants of the traditional procurement methods, as evident from the percentage of contracts distribution according to procurement routes shown on Table 1. Figure 1 compares the total percentage distribution of contracts procurement patterns according to the generic classification system, for 2004, 2007 and 2010 surveys. On the average, over 75% of the contracts are procured through traditional methods.

Also, a recent survey carried out by the Royal Institute of British Architects (RIBA) Plan of Work Review Committee amongst her members (RIBA, 2012) corroborates the RICS results, as shown in figure 2. This figure shows that 86% of architects frequently use the traditional method in their projects execution. Also, architects who were engaged through the one stage design and build and two stage design and build (where O&M services are also procured separately) were respectively 41% and 39%. Whereas, those who used the PFI route which tend to promote high quality maintenance were only 10%.

Table 1: Trends in Methods of Procurement by number of Contracts

	Type of Contract	1985 (%)	1987 (%)	1989 (%)	1991 (%)	1993 (%)	1995 (%)	1998 (%)	2001 (%)	2004 (%)	2007 (%)	2010 (%)
Traditional	Lump Sum – Firm BQ	42.8	35.6	39.7	29.0	34.5	39.2	30.8	19.6	31.1	20.0	24.5
	Lump Sum – Spec & Drawing	47.1	55.4	49.7	59.2	45.6	43.7	43.9	62.9	42.7	47.2	52.1
	Re-measurement – Approx. BQ	2.7	1.9	2.9	1.5	2.3	2.1	1.9	1.7	2.9	1.7	0.3
	Prime Cost Plus Fixed Fee	2.1	2.3	0.9	0.2	0.3	0.7	0.3	0.2	0.2	0.5	0.6
	Management Contract	1.7	1.2	1.4	0.8	0.9	1.2	1.5	0.6	0.2	0.7	0.0
	Construction management	-	-	0.2	0.2	0.4	1.3	0.8	0.4	0.9	1.1	0.3
Design & Build	Lump Sum – Design & Build	3.6	3.6	5.2	9.1	16.0	11.8	20.7	13.9	13.3	21.9	17.5
	Target Contract	-	-	-	-	-	-	-	-	6.0	4.5	3.7
Single point	Partnering Agreement	-	-	-	-	-	-	-	0.6	2.7	2.4	1.0
	Total	100	100	100	100	100	100	100	100	100	100	100

(Source: Langdon, 2011; Langdon, 2012)

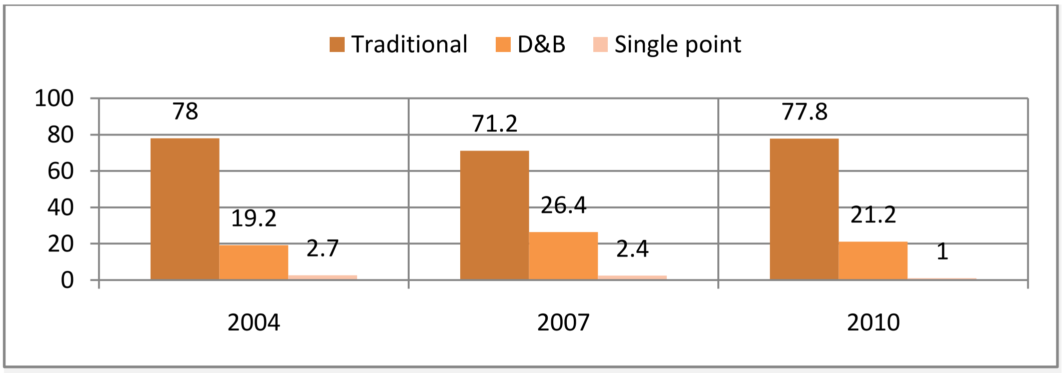

Figure 1: Total % of Contracts Distribution According to the Generic Procurement Routes from 2004, 2007 and 2010 RICS Survey Data

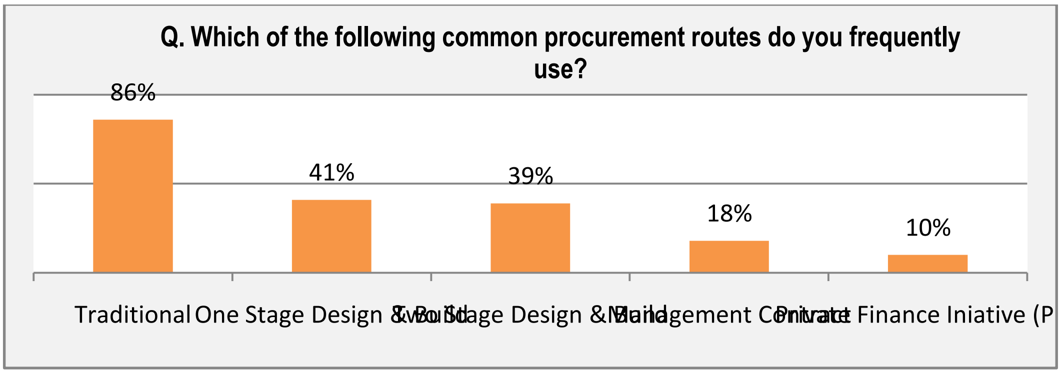

Figure 2: Procurement Routes Frequently Used by RIBA Members (Source: RIBA, 2012)

It therefore becomes pertinent to explore other avenues of integrating maintainability and operability across all procurement routes, particularly for low carbon buildings which requires more attention to maintainability than the traditional buildings.

3.2 Involving Facilities Management Personnel at the Design Stage

The increasing awareness of the need to operate and manage facilities for long periods no doubt requires the involvement of Facilities Managers (FMs) in the design process (El-Haram and Agapiou, 2002; Enoma, 2005; Jaunzens, n.d.). According to Enoma (2005), involving the FMs at the design stage will not only add value to the facility, but will consequently ensure less 'rework', emphasise value for money, efficient control of the supply chain and teamwork. Enoma (2005) added that FM practice borders on achieving better facility that that is easy to operate, maintain and manage by applying whole-life costing and risk management techniques. Involving the FM skills in design process is seen to be capable of improving the way buildings are designed, built, commissioned, maintained and refurbished (El-Haram and Agapiou 2002; Jaunzens n.d.).

El-Haram and Agapiou 2002 also highlighted details of the procurement and contract management tasks of the FMs or their roles at the project planning and design stage to include among others, the following:

- reviewing and assessing the design from maintainability, maintenance, operability and serviceability point of view
- identification and selection of the optimum maintenance and replacement strategies for the facility
- liaison with the design and construction team to select the cost-effective design option which will optimize whole life costing

However, response to the call for facilities managers to be involved in the design process across the globe has been very lethargic (Mohammed and Hassanain, 2010; Silva, 2011). Also FM practitioners are seldom involved in briefing, and by extension design (Bordass, Leaman and Eley, n.d.). So there is the need to explore a process that could facilitate the involvement of the Facilities Managers in the design process, which will no doubt ensure maintainability of low carbon buildings.

3.3 Post Occupancy Evaluation

Post Occupancy Evaluation (POE), also known as Building Performance Evaluation (BPE) (BSRIA, n.d.) involves a systematic evaluation of opinions about buildings in use, from the perspective of the people who use them (postoccupancyevaluation.com, n.d.). It evaluates how well the building matches users' needs, and identifies ways to improve building design, performance and fitness for purpose (Ibid). POE is used to evaluate new and old buildings when they are fully operational; preferably, not less than 12 – 15 months of occupancy, in which period users must have adequately experienced and adjusted to their new environment and also allows for a full circle of the seasons (SGV, 2010).

Preiser (1995) noted that the POE is a tool which facilities managers can use to assist in continuously improving the quality and performance of the facilities which they operate and maintain.

The benefits of POE clearly show that it can inform maintainability in future designs if properly carried out, documented and made accessible to design professionals. However, it must be noted that the responsibility for initiating POE rests with the facility owner (SGV, 2010). He also funds the exercise, and will therefore be naturally reluctant where the essence of POE is to better future building and not his particular building, except for a corporate body client that is in continuous development exercise or a professional developer. Bordass and Leaman (2005) noted some of the notions expressed by clients, which among others include:

- That the name POE was seen as academic, and too late to benefit the project concerned.
- Client did not appreciate why they should pay designers for POEs on recently completed buildings when this would benefit future clients more than themselves.
- Clients feared that feedback information would remain on the shelf and never get used
- They did not see why they should be called up to tackle the problems of the construction industry".

In practical terms, very few POEs are undertaken because even designers are also afraid of the risks of liability and of voiding their insurance (Bordass, Leaman and Eley, n.d.). It has also been noted in literature that the results of POE exercises are not readily accessible to those who need them for future projects (Ibid).

BSRIA (2007) also argued that whereas "*POE is certainly useful for researchers who want to find out what worked and what went wrong in a building, for building designers, it is more of a case of shutting the stable door after the horse has bolted".* The authors added that, it is possible to make some improvements and fine-tuning from the evaluation outcome, but this may be too late for major changes, should the need arise.

Also, it must be noted that whereas there are many common futures in buildings, including the technologies, each building is still unique in itself as site; building orientation and method of construction differ even for buildings of close proximity and of the same typology. Building designers' drive for creativity and innovations will definitely produce dissimilar buildings. So lessons learnt from earlier projects may not be sufficiently adequate to ensure operability and maintainability of the new project; no doubt, it may help to some extent.

If there is therefore a process is in place that ensures that maintainability issues are prerequisites, the design team will have no choice than to ensure that POEs are carried out and made reference to for future designs.

3.4 Life Cycle Costing (LCC)

Life Cycle Cost has been termed as Real or 'Ultimate life Cost (Seeley, 1996). Holti, Nicolini, & Smalley (1999) describes it as 'Through-life Cost'; it has also been referred to as 'Whole-life Cost' (BSRIA, 2008). In this section and all through the document, the terms are interchangeably used.

LCC is defined as *"the present value of the total cost of an asset over its operating life, including initial capital cost, occupation cost, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life"* (Seeley, 1996). A similar terminology often confused with LCC is Life Cycle Assessment (LCA) which involves viewing designs in terms of the long-term environmental and economic benefits of the designed asset (Wang, Chang, & Nunn, 2010). Other terms used to describe life cycle assessment include: life cycle analysis, life cycle inventory, ecobalance, cradle-to-grave analysis, well-to-wheel analysis and dust-to-dust energy cost (Greenoptions.com, 2011). The LCA concept applied to building design suggests that the design must be cognizance of not only cost and maintenance, but also, its impact to the environment during construction and operation stages. These environmental impacts include energy involved in the manufacture of components parts.

More often than not, building developers base their judgments on only the capital cost without consideration to the cost of running and keeping the building (Arditi and Nawakorawit, 1999). Bokalders and Block (2010) argued that this capital cost usually comprises of just about 10% of the total cost of a building calculated over a 50 year life cycle. 50 – 80% of the real cost is spent during the operational life of the building (Silva, Dulaimi, Ling & Ofori, 2004). Despite the varying statistics, it is clear that the cost incurred during the operational life of a building exceeds the cost of design and construction and so cannot be ignored. Silva et al (2004) posits that LCC approach should be incorporated into the procurement procedure at the tendering stage and that if implemented, is capable of providing motivation to improve maintainability.

However, NIBS, 2010 has posited that LCCA is especially useful when project alternatives with same performance requirements and with varying initial and operating costs, need to be compared with the view of selecting one with maximal cost savings.

Also, RIBA (2009) has argued that life-cycle costing (LCC) or whole-life costing (WLC) is a 'money-based measurement' and does not take into account, important factors like the damaging impact of CO_2 emissions. It further explained that whereas the initial construction cost could be estimated with reasonable accuracy, the cost-in-use (operation and maintenance cost) could be more difficult to estimate due to future uncertainty. RIBA further advocates for life-cycle analysis (LCA) as a better approach.

To conclude, neither the LCC nor LCA approach can wholly enhance maintainability, but are essential aspects of maintainability considerations. The LCA approach which is described by Wang et al (2010); and IAI (2011) as involving the environmental and economic factors should be seen as very vital in the maintainability considerations for LCBs and can better be considered along with other maintainability factors to ensure maintainability of LCBs.

3.5 Maintainability Scoring System

The concept of maintainability scoring was initiated in Singapore, following the recommendation of the Construction 21 (C21) Steering Committee (Silva et al, 2004), set up with the mandate of re-inventing Singapore's construction industry (SNEF, 2010). The maintainability scoring system (MSS) is to provide objective measures of maintainable designs (Silver et al, 2004). Complementing the C21, the National University of Singapore through several researches developed the MSS for various elements/components of a building which it classes as; façade, basement, internal wet area, roof and M&E System (Das and Chew, 2007; Chew, 2010).

The system relies on a comprehensive database of material manual and defects library (Chew, 2010). The MSS is applied during the design stage to inform choice of a better maintainable design option, and also at the construction stage to enable further improvement on maintainability (Silver et al, 2004).

The MSS concept logically appears to present good potential for maintainability, however, all available literature seem to portray that this system is applicable only in Singapore. No literature has been found that indicates its applicability anywhere else in the world. However, it is a system that is worth exploring.

4. Conclusion

The paper has indicated that building maintenance is not just only an under-researched subject, but often treated with levity, and that the growth in awareness of its importance is yet to be matched with sufficient research and development, particularly in the current age, when buildings are fitted with new and innovative low carbon technologies. The paper also presents fears expressed by experts in sustainable buildings, indicating that LCBs could be uneconomical to maintain, with poor indoor air quality and other unintended consequences, thus creating homes that may be unfit for people. The concepts of maintainability and operability were also discussed as being design focussed; aimed at meeting the objectives of building maintenance, from the design stage. The paper highlighted that maintainability has been an age-long traditional requirement for building designs, and the obligation for designers to deliver maintainable assets are already enshrined in law, yet often not well done.

Some strategies developed to optimise maintainability were also reviewed and found not to have been effective.

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