Engineering Defects- Costs and Sustainability

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Abstract

This paper focuses upon building services engineering defects within industry and how they are perceived and understood.

As building services evolve to meet ever growing best practices and sustainable engineering principles it is expected that project defects would be steadily reduced. Within industry this is not always the case, resulting in frustration for all parties.

Definitions of defects are explored, why they occur and perhaps more importantly what consequences they carry.

The findings suggest that direct and indirect costs applied to defects are considerable. Differences in opinions and responsibilities are common causal factors with lack of communication sitting at the forefront.

Defective engineering services not only affect sustainable outcomes and energy efficiency, but also require re-work. Visible costs associated with completing work twice can be significantly high. Indirect costs may be much higher.

Keywords

Defects, facilities management, maintenance, re-work, commissioning errors, handover procedures.

1. Introduction

The achievement of sustainable buildings is proving to be a challenge to construction professionals. *[i]* There is important data available which identifies how buildings actually perform compared to how designers had envisaged they would perform. A gap between actual and design performance has been identified. This “Performance gap” has initiated much research aimed at finding causes and solutions. Buildings and their engineering services are complicated, multi-disciplinary projects and, as well as requiring accurate technical engineering input, the process of construction includes many interfaces and interdependencies between disciplines. Given that building services systems are dynamic and direct users of energy, their post-handover operation has a major influence on energy use in buildings. Despite some seminal studies into the construction industry, which have compared construction to manufacturing, it is accepted that perfection will not always be achieved during construction phase and defects will occur. Contracts are designed so that, ideally defects will be remedied within an agreed period to the satisfaction of both client and contractor. A working definition for Practical Completion *is*: “when no defects are apparent and when such minor items as are left to be completed can be completed without any inconvenience to the employer using the building as intended” ***[ii]***. This definition could be said to recognise that the construction process is not perfect and it is therefore sensible to design contracts to which recognise imperfections and include methods for resolving them.

However, the concept of defective building services engineering plant and sustainable buildings are contradictory terms. In order to close the “Performance Gap” must there be an improvement in getting it right first time? When purchasing manufactured goods, most people expect a defect-free product and is it unreasonable for a construction client to expect a similar attitude to the finished product? After all, it is not like services engineers welcome the problems involved in “closing out” defects. Is there something about building engineering services projects that make defects inevitable?

This paper examines what constitutes a defect, why do they occur and what are the direct and indirect costs. The paper recognises the potential benefits from the BIM and Soft Landing initiatives but proposes that designers should also have a greater awareness of the resources that will be available to Facilities Managers

2. What is a defect ?

Several researchers and writers have produced definitions for construction defects. None are particularly contradictory, however it is useful to consider these various meanings because this can contribute to an understanding of why they occur. It is suggested that ***[iii]*** “a defect can be defined as an unacceptable deviation from specified requirements”. It is also referred to as “the absence of something essential to completeness, a lack or a deficiency arising from an incorrectly designed or built component of a building - a product of fault. ***[iv]***"

Is it important when a defect occurs and when it is resolved? A further definition differs slightly to the abovementioned : a defect may be considered as "a shortfall in performance which manifests itself once the building is operational" [***v***]. Atkinson describes failures during construction not as defects but rather as items which should be corrected before the project is handed over. This approach has some similarity to manufacturing in which the purchaser of an item is not normally aware of any design development or manufacturing problems. Just the same, rework during the programme will still have some additional cost, though this is likely to be a lesser amount than that for work that requires a revisit to an occupied building where resources and equipment may not be readily to hand.

Carrying out rework of building services system during a contract programme is often completed under pressurised conditions. Under these circumstances there is a possibility that work may completed in the most expedient way. For example, if time is critical there may be a temptation to provide a "site solution" to a problem which should really be referred back to the designer. Too many of these events could have a substantial effect on building services systems and work against the original sustainable ethos.

3. Why do defects occur?

A strategy for preventing, or more realistically managing defects should start with an analysis of why defects occur. It is considered that the reason behind defects are poor design, specification shortfalls, incorrect selection of materials, poor workmanship and poor supervision [***vi***]. All of these reasons have plausibility but it is worth noting that they can relate to almost all phases of a project.

It is also accepted that [***vii***] defects can result from bad practice throughout all stages of any specific project. However, they can be apportioned into three problematic areas:

- Product failure is responsible for "10%" of defects
- Design errors are responsible for "50%" of defects
- Construction phase on site decisions are the cause of 40% of defects

Human error is considered to be a fundamental reason why defects occur within the construction industry, and that a central factor is managerial failure [***v***]. "When a managerial error occurs high in the managerial chain, it creates *noticeable influences* on the number of errors occurred by the "hands-on" staff.

Whilst none of the above analyses of the causes for defects necessarily conflict, Parsloe [***viii***] provides a practical approach by grouping causes under four headings, human error being a thread linking each of the four categories.

- Design deficiencies
- Material deficiencies
- Specification problems
- Workmanship deficiencies

In a paper presented at the 2013 CIBSE by Arnold, D [***ix***], a similar list of causes is quoted. However, Arnold also includes incomplete or inadequate commissioning and poor maintenance in operation as factors that may cause reduced or defective performance. That David Arnold's paper dealt with air-conditioning systems perhaps highlights the fact that the long-term performance of building engineering services can be heavily dependent on handover and maintenance procedures.

4. Design deficiencies

Design is fundamental function in the construction process and affects every event downstream. It is considered that some, though not all of the critical process which are dependent on design decisions are: material selection, how, or if, specifications can be complied with, and how plant and equipment is installed [***vi***].

It is believed that design problems can be initiated at the very outset of the project [**i*v***]. It is argued that from the time when the design team first meet to discuss needs, objectives and to prepare a business case, a clear understanding of client requirements and business needs is vital. If this is not the case, the scene is set for flawed proposals.

It is suggested that a common problem associated with designs at the early stages of a project is that simple design considerations during the conceptual stages are commonly not tackled until the detail design is produced. Instead, the concept design team tend to focus primarily on major design strategies. If simple design considerations are ignored during strategy proposals they may grow into “discordant detail-design problems”. Those members of the design team who must prepare detailed proposals can rely heavily on the quality of the conceptual brief and associated documentation such as meeting minutes.

Design considerations associated with the occupier and facilities management team are essential during all design stages. The sooner key consultants and maintenance teams are appointed the better.

The design stages within UK construction industry have typically followed the RIBA Plan of Works. It is essential that detailed design programmes are drawn up as early as possible so that critical dates are recognised. A famous military saying is that no plan survives contact with the enemy, so it should be remembered that programmes are management tools. When designs are rushed to meet immovable deadlines, the quality of work can suffer. Far better to match resources with job needs.

Of course the client has a key role. Late design requirement changes may add to already pressurised design programmes.

5. Material deficiencies

Materials defects commonly occur because designers do not consider how materials will behave during construction and during the life of the building [***iv***]. It is also believed that material defects are commonly caused by the effects of material incompatibility [***x***]. Specifications should be based on knowledge, not only of material performance, but they should also aim to prevent poor manufacturing techniques and poor installation methods.

Ideally, when the design team are selecting or approving materials for any given construction project they establish that the material or item of equipment is fit for purpose i.e. will it do the job it is required to do. Training and experience are vital here, though material science is a discipline which may require input from experts.

The onsite workforce should be fully familiar with the characteristics of the materials they are installing. It is important that the management team ensure site staff are suitably trained and aware of how the equipment is to be installed. Though it may be considered to elementary good practice, it is important manufacturers' literature is absorbed and understood before installation. Fixing and mounting equipment correctly can significantly help to minimise failures.

Materials supplied by manufactures do have failures, although they are commonly due to a component or part of the material or equipment failing and not the equipment as a whole. Specifically within the building services industry many items of electrical equipment such as light fittings are supplied with internal electronic components such as resistors, diodes and fuses etc. These internal components of equipment are all type tested before being built into the complete fitting and the light fitting is tested as whole once built. Usually only batch tests are carried out when testing these electronic components which means some defective components may slip through for sale.

6. Specification problems

A solid specification should begin to be established at the start of the conceptual design stages. When the proposed contractual arrangement is clear, this can affect how the specification is developed. All contracts are commercial in nature and therefore money and economics must be factored into the process. Tendering and contracts arrangements that squeeze contractors can lead to specification adjustments perhaps dictated more by financial pressures than by good engineering practice, particularly where project expectations differ from party to party. Post –

tender design disputes do not necessarily create conditions for ideal outcomes for clients. Value for money may not always be achieved by forcing down tender prices or consultant fees.

It is believed that design and build projects which do not have tight specifications can prove to suffer from post – tender differences in design interpretation with a consequence of increased defects [***vi***].

Work packages which are incomplete, or have not been developed as part of an integrated holistic project design may lead to incomplete information, late changes or an inaccurate assessment of the quantity of work.

Time and effort in preparing client requirements should avoid the charge that the specification never adequately explained what was wanted. Designers must ask the right questions in order to prepare contract proposals.

Design teams sometimes over specify systems. “Adding a bit for luck” has almost been standard practice in some building services engineering design offices. The nature of the industry and the process of design does not encourage risk-taking: far safer to make sure that the boiler/chiller/fan/pump etc. will always meet the load. Margins can have a cumulative effect. Solutions to the practice over over-sizing may be contractual rather than technical. The term “oversize” occurs frequently in building services publications. CIBSE Guide F [***xi***] “Energy Efficiency in Buildings” contains the term “oversized” more than 30 times, which in most case is cited as a cause for inefficient plant performance. BSRIA also warn against excessive design margins. The BSRIA/CIBSE publication “A Guide to HVAC Calculations” (2012) advises that excessive margins can lead to poor plant performance and control.

Defect closing teams may be in an ideal position to analyse what works and what doesn’t. Feeding back information about buildabiity and commission-ability, could benefit future designs. Also, the process of commissioning could provide feedback where margins have been applied to systems.

7. Workmanship deficiencies

Poor workmanship can occur resulting in defective systems or latent defects. Many design teams are now commonly over specifying systems in a fail safe manner to allow specific redundancy due to these failings.

Common causes for poor installation techniques are inadequate training, programme constraints, cost constraints and design ambiguities [***vi***].

The construction industry functions on skills and knowledge. Training at all levels is essential. Statutory and non-statutory regulations and guidance are regularly updated. Adherence to regulations does not appear getting easier. Additionally, innovative products and systems are constantly being brought into the industry. A successful project relies on competent designers, managers and skilled tradesmen.

7.1 Human error

In any endeavour the risk of human error must be a factor. An awareness of the possibility of human error does not suggest poor competence, rather a realistic assessment how actual construction projects are managed. Management procedures must be capable of preventing the “never event” errors whilst coping with errors that can be relatively easily resolved with no physical or financial danger to any party. Of course tiny problems, if not reported can create much larger problems downstream. Staff should be encouraged to “come clean” when mistakes are made.

Research has been carried out into the effects of human error and its impact within the construction industry [***v***]. It is suggested that, a large amount of emphasis is placed on how to rectify a defect or error once it has occurred rather than understanding the reason or individual that led to the event. The research further concluded that managerial failures are a major reason behind defects. From interviews with managers the most common causes for defects were seen to be, in descending order: poor formal communications, site operative errors, time pressures and faulty work inspections.

It could also be concluded that there is no simple, single reason why defects arise. However, they do tend to fall into three broad categories [***v***]:

- **Simple self-contained errors**-for example a slight management mistake which is picked and corrected by the site team with no publicity
- **Two-way interactions**-these kinds of mistakes involve a combination of errors by management and the site team
- **Complex interactions -** a worst-case example of this type of issue could be a problem which has been initiated at design and then further compounded by poor management, poor site supervision and, perhaps even poor workmanship.

It is interesting to observe that the research recognised that poor communication was an important factor in human error situations.

8. What is a defect and what is maintenance?

Some care is necessary in determining the responsibility for faults. Contractors should be aware of their duty as should the FM team. This is not always as clear as it might be but there is a difference between a genuine defect and a nuisance claim *[**viii**]*. This an area of customer care where a good defect management policy can pay dividends in terms of trust and goodwill.

It is believed that client training and the handover process are of fundamental importance when ensuring that the FM team is fully familiar with the completed building services engineering systems and associated maintenance requirements [***xii***]. Contractors must understand the complexity of systems from the viewpoint of the people who are to take responsibility for operation and maintenance. Clearly, this complexity can be reduced if FM engineers are involved much earlier in the process. In fact, FM involvement from feasibility onwards can pay off, not only in customer relations but also in design improvements. Research has suggested that "well intended design features commonly fell at the first fence when used by non-architects"[***xiii***]. This draws the thought that system designs potentially could be becoming too complicated for users and if inadequate training is given can lead to systems failures and nuisance claims of defects.

A criticism of client familiarisation sessions is that the wrong people attend. Often these events involve representation of senior managers from the FM side, but not enough of the staff who will be responsible for “hands-on” maintenance and operation.

9. The impact of defects - costs and damage to reputation

Defects in the UK construction industry cost at least £20 billion pounds annually [***xiv***]. Previous research linked defects to quality and recommended that defects should be reduced by 20% annually [***xv***]. Unfortunately 14 years since the report was produced defects are still very much a problem within the construction industry and still constitute significant costs. These costs may be incurred during the construction phase or post completion. A well- managed defects policy should mean that costs incurred during project delivery could enhance, or at worst, limit damage to business relations between contractor and client. Post contract defects may be more visible and could have a greater risk to reputation and good will.

It would be naive to expect that in complicated building projects no defects would exist after handover. However, besides the direct costs involved in repairing errors, the indirect costs to reputation, good will and the possibility of further work could be much greater.

When defects occur within industry they can create unwanted tensions between parties. Research suggests that where defects arise resulting in major problems and if not managed appropriately “generic customer dissatisfaction” may occur [***vii***]. This may result in the client not using the services of the contractor again. In order to gauge the performance of contractors, Key Performance Indicators (KPI) were created by Construction Excellence. This allowed clients to score contractors based on performance within given projects. KPI’s provide potential clients with data on which to perform in specific areas such as safety and defect management. It is believed that when clients are analysing potential contractors for a project, having the correct track record of delivering a job can mean the difference between winning and losing a project [***xvi***].

10. Rework

The financial implications of defects are often identified as simply the money held over for the defects period. A fact that may sometimes be overlooked is that, in some cases the practical implications of defects for an installation contractor is that the same work is done twice. Since tender prices would normally be based on operations being completed correctly first time, this rework could have significant financial implications.

Rework is commonly defined as "work that represents the unnecessary effort of redoing a process or activity that is incorrectly implemented the first time" [***xviiv***].

One researcher looked at gathered data from various other researchers regarding the costs of rework [***xviii***]. The table below has been compiled from this paper.

Source	**Impact on Project Performance**
Josephson et al (2002) [***xix***]	The cost of defects identified from 7 building projects in a Sweden based study ranged between 2.3% to 9.3% of contract value. In another Sweden based study , the quality failure costs were found to be 6% of original contract value
Rhodes and Smallwood (2003) [***vii***]	(In a South Africa based study, the cost of rework was found to be 13% of the value of completed construction. In the same article it was reported that the Associated General Contractors of America found the average cost of rework (from nine industrial projects) was 12.4% of the project cost
Marosszkey (2006) [***xx***]	In this Australia based study (New South Wales), the rework costs on average were found as 5.5% of contract value

11. Reducing or eradicating defects before they occur

Can defects be completely eradicated? For complicated, multi-disciplinary commercial projects it is highly unlikely that all of the technical and sequential risk areas can be eliminated. However, it is not over-ambitious to suggest that a defect management policy can ensure that defects are minimised, resolved and learned from.

Firstly, the industry needs to buy into the mentality that good quality of work and being a good client go hand in hand. During the Commons Reception of the 10th anniversary of the Re Thinking Construction Report, it was suggested that in order for the construction industry to move forward and become fully competitive, lowest cost tendering needs to be re thought [***xxiv***]. Perhaps a similar approach should applied to design consultant commissioning agreements.

Lowest cost tendering forces the hand of all parties involved in the supply chain. This is not an original idea but does demand a re-think of how the industry is perceived from within as well as from outside. It raises questions which range from professional recognition to vocational versus academic education- a strange situation given that the majority of the UK population rely on the technologies that form the built environment.

Secondly the design team need to place greater emphasis on the preliminary discussions at the start of a project. The client must be fully involved in these discussions. At this stage it is necessary to consider if client requirements are fully evaluated to see if they are feasible, not just during the concept stage but all the way through to the detailed design stage. Note taking and distribution to all parties during the preliminary discussion process (in the form of meeting minutes) is essential. This process should identify and consider all critical aspects. It is vital that all parties are fully informed.

Following this methodically and critically produces a solid structure upon which to develop project and eliminate errors long before a shovel hits the ground [***xvi***].

(ibid) also suggests that involving key subcontractors early within the design stage to provide technical input can help the design flourish and creates a “good working relationship” which he believes is “fundamental to the coordination of the design and permits the efficient use of design resources and skills.” The importance of early involvement of the FM team has previously been mentioned.

12. Closing out Defects

It has been stated that total elimination of defects is an impractical ideal. It is therefore essential that when defects occur successful methods of tackling the defects are put in place.

Poor management of defects can be the difference between a successful project overall. Although a project may be deemed successful at handover, it can rapidly become unsuccessful as a client’s enthusiasm can quickly turn to disappointment. Some parts of the construction industry have had a poor reputation with regard to defects and after sales service [***xvii***].

Over the years there have been many techniques developed in how to manage and close out defects, from setting up simple spread sheet systems which record and monitor defects to intelligent document control software packages which can, not only record when defects are raised or closed, but also can also issue electronic notifications to the necessary parties. Both systems are still commonly used but their success depends on how they are managed.

It is believed that a "maintenance supervisor" can play a vital role and should take responsibility after practical completion and for the whole of the defects liability period [***xx***]. This approach provides the client with a specific contact, whilst also allowing lessons learned to be incorporated into new projects. It is suggested that adopting this system will improve efficiencies in a new project because "teams will not be carrying the luggage of the previous project with them" (ibid). It is argued that additional cost will be offset by a reduction in money on retention and increased customer satisfaction.

At first sight this might suggest a mopping up exercise, however (ibid) points out that in order to achieve a "Perfect 10" in KPI measurement for defects they must be progressively remedied throughout the project.

13. The Views of Construction Professionals

So far this paper has tended to explore the work of academics involved in the science of construction management. Perhaps some balance will be provided by examining the views of construction professionals with relevant and recent experience of these matters. A series of interviews with building services engineers and other construction disciplines which include:

- Main contractors
- Building services contractor
- M & E designers
- Facilities managers
- Client project manager

13.1 Interviews-analysis

There was general agreement that poor defect management policies "can taint a client's perspective", and that this could seriously hamper future work prospects. Interviewees also tended to agree that the industry could still do better, citing that reaction times were not always as speedy as they could be.

However, it was largely agreed that the industry was definitely moving in the right direction, partly driven by a combination of a greater contractor awareness of the importance of a good defect policies as well as client expectations. A small minority of interviewees suggested that some improvements were cosmetic and that electronic systems generated impressive reports rather than practical results.

As far as types of defects were concerned, all interviewees maintained that heating systems always reported defects. Fire alarms, CCTV and lighting problems featured widely. It appears that experience of defects was in proportion to the contract value of the system and the potential damage risk. Leaking heating systems could cause expensive damage to fixtures and finishes. The discipline of the interviewee also appeared to influence their opinion.

A common theme amongst those questioned was that training, both for client and contractor. BMS systems were cited as an area where client training before and during handover could be critical. One interviewee felt that there was a significant skills gap between staff providing familiarisation training and those attending. This raises several interesting considerations. Should more time and expense be devoted to skills training of maintenance staff, or should systems be simpler? Early involvement of FM engineers might provide a solution, though the interviewees considered that FM had a responsibility for staff training and over-reliance on " a handyman" to cope with complicated electrical and mechanical plant was unwise.

The interviewees raised the question of whether familiarisation training should be client driven or contractor driven. However, "do clients know the right questions to ask". This may be code for identifying who will fund the process. Good maintenance was recognised by all as a vital component of post-handover for projects. From a contractor's point of view this would reduce the instances of defects being conflated with maintenance tasks.

The emphasis with which the interviewees placed on familiarisation and good maintenance indicates that many "defects" do not necessarily meet the definitions discussed earlier but are more likely to be operational issues. Continuing this theme, it was suggested that handover and maintenance information could be improved: for example training sessions could be videoed. Further, the training of FM staff could also involve working alongside contractors during the installation and commissioning phases. Another suggestion was that fault-finding training could pay off in terms of avoidance of blame and speedy problems resolution.

It might not be a surprise to learn that building services engineering professional cited programme pressures as a factor in defect resolution. In particular there was concern about how commissioning periods are often compressed, and this is often because non-engineering disciplines failed to appreciate the importance of thorough commissioning for engineering systems. In defence of building contractors, it was also agreed that lowest tender type contract were also responsible for pressurised programmes.

Tight budget concerns also raised criticism of value engineering process which were often seen as simple cost cutting rather than improving value.

Most of the interviewees said that they had never worked on a zero defect project. Where a zero defect project was referenced it was explained that this was because the contract budget allowed for progressive snagging and sufficient commissioning time.

14, Conclusions

The nature of the building industry means that it is highly unlikely that the transfer of a building project from feasibility to a functioning building will be a perfect process. Where this “lack of perfection” is caused by poor design, poor workmanship or by poor handover procedures, this should not be acceptable.

Building services engineering embraces various mechanical and electrical technologies which must interface with each other as well as co-ordinating with building features and construction operations. In other words, it can be a complicated business which requires the highest project management skills. Defect management is one of those skills. A good defect management policy should firstly aim to eliminate defects and, where this is not possible, ensure that the product eventually occupied by the client is not adversely affected by any faults or errors caused by the contract team. If a building is designed to be sustainable it must function as it was designed.

The direct and indirect costs associated with defects are considerable. Causes and responsibilities can be convoluted and difficult to resolve. In order to develop methods of identifying defects, this paper has looked into typical causes. Design, workmanship , commissioning and handover procedures are not unexpectedly part of the problem. However, there is a marked difference in emphasis between academics and construction professionals. Construction professionals find it important that skill and knowledge levels of the FM team must be in balance with the technologies included in the building.

An agreed balance between design sophistication and FM skills available should be resolved at feasibility / design stage. At this stage sufficient project information should be available so that FM managers can make an informed judgement about the level of maintenance resource that will be required. The link between building design and building operation should be stronger. The skills and knowledge required at early design stage are considerable. Improving these skills requires greater feedback and input from engineers with experience in contracting, maintenance and building operation.

In terms of sustainability, defects could be considered not simply as contractual matters which occur within projects, but an index of a philosophy that underlines contractual practices. These practices may not have developed from within the construction industry but may be more influenced by outside authorities who control finance. Clearly, building services engineering systems which do not achieve design performance will adversely affect the carbon footprint of a project. However, the causes behind defects are not always straightforward and the realisation of a zero-defects policy can only be achieved if all parties within the supply chain play their part..

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