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DENMARK

Aalborg Universitet

CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 8

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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 8*. Department of Civil Engineering, Aalborg University.

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Reducing the Performance Gap By Design For Commissioning

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Abstract

Incomplete commissioning can be a contributory factor to infamous performance gaps between design promise and actual building performance outcome. Some of the problems with the commissioning process can be traced back to design decisions taken without recognition of their significance for getting the building to work. Design for commissioning is now being explored by major designers and contractors as an integral part of design for manufacture and assembly. The approach is likely to be complemented in the future by the use of portable wireless sensor networks that relax the expensive data acquisition requirements of a full 'design for commissioning' approach would entail.

Keywords - commissioning; energy performance gap; design for manufacture and assembly

1. Introduction

It is widely recognised that real buildings often deliver disappointing performance when measured against design expectations. The broad reasons are now well understood (1):

- 1) The design figure used estimates for factors that were not well known at pre-tender stages when the performance was computed.
- 2) There may have been modifications to the design during construction.
- 3) There may be unexpected use patterns when the building is occupied.

However it is also recognised that commissioning of the building may not have been complete. 'Commissioning' has been described as 'the advancement of the installation from the stage of initial static completion (i.e. 'is it there?') to full satisfactory working order to meet specified requirements' (2). Commissioning usually progresses as far as 'setting to work', but may not always have time to validate or optimise the installation. Matters are not helped by several of the other problems (1) – (3) compounding to the difficulties in completing the commissioning task.

To improve overall construction performance, it is now common practice on large projects to bring forward contractor expertise into the

design stage. This improves build-ability of the final design. This paper explores the feasibility of similar efforts to improve the ‘commission-ability’ of the design. The plan of the paper is as follows. We first describe the commissioning process from a novel formal point of view. We then establish that the economic pressures on the project make it very unlikely that, if commissioning is treated as a distinct end process, it will be completed before handover. We then look at a number of factors that, through design, improve the process and pre-handover performance. The paper highlights how ‘design for manufacture and assembly’ could facilitate this process. But we argue finally that the process inevitably implies planning for some post-occupancy commissioning and point to new techniques, which avoid investing in uneconomic levels of data acquisition.

2. Commissioning as a Fault Finding Process

A conventional representation of Commissioning is as a series of logically ordered stages (e.g. CIBSE Commissioning Codes (3)). This approach reflects a natural engineering logic within the system. Until the system is powered up there is little that can be done to set plant to work. Until the plant is charged with refrigerant and water, it is not possible to balance circuits. But this procedural approach also reflects the viewpoint that if everyone has completed the job they were contracted to do, then much of the commissioning process is an orderly ticking of boxes much as in a Quality Assurance scheme. A QA system is relatively easy to fit within a project management system. Site observation by the authors of commissioning tells another story.

Commissioning is not just a matter of affirming components are present and that they power up when switched on. In actual practice, it contains a strong element of fault finding, forensics and then correction. Commissioning practitioner shadowing and interviewing by the authors showed that while the commissioning measurements are relatively straightforward by themselves, a lot of external factors can cause delays in the process:

- System installation is not completed on time or elements are missing (e.g. no power to test fan, no plug at the end of fan electrical cable, drain system not installed before flushing, BMS sensors missing or not connected)
- System improperly installed (e.g. fan wired the wrong way around)
- Equipment and or documentation needed for the tests not available (need not foreseen or equipment borrowed by other subcontractor), resulting in delay because of the time needed to find the equipment on site (e.g. ladder, platform) or because of the time to go back and forth to the office (could be up of 30 min way and back from the furthers end of the construction site on such a big project as an airport terminal)
- Need to wait for a person with specific competence or accreditation to start the test (e.g. electrical power up, client witness). Causing delay because

the person is busy somewhere else or bad synchronisation of breaks. For equipment installed by small subcontractor that are not on site at all time this can mean several days of delay until they can send someone back.

- Previously commissioned systems has been partly decommissioned by another subcontractor

- The measurement points are not accessible (e.g. finish has been installed before commissioning was over, key to the plant room was lost) or require access equipment that is not necessarily available (e.g. ladder, platform lift.)

- The main means used to communicate with each other is cell phones with associated battery and reception problems

As a consequence, while it may be easy for the project engineer to estimate the *minimum* time to commission a perfectly constructed building, the actual time to fully commission a real building could be much extended.

The indeterminate length of time to be allocated to full commissioning presents a problem for the project manager. Much earlier in the construction process, incurred delays can be managed by a recovery plan that devoted more resources to later stages so as to catch up on the client's timetable. But uniquely there is no latter stage to commissioning. The implied cost penalty to the client of delaying occupation would usually far outweigh the imperfect performance of some part of the system, given that, in principle, it could be sorted out later. There are possibly only two exceptions. One exception would be any flaw that made the building unsafe. Another would be a flaw that required major re-engineering and a cost of the disruption that might just swing the balance back to solving the problem before handover. Otherwise there would seem an inevitable risk of spill over of issues into occupation.

In designing for commissioning, we need a more realistic conceptual model of the process than the prescribed commissioning plan. The proposal here is to treat it as an instance of a fault finding process. Its driver is that the process must be terminated at a fixed time, while using a fixed resource, with the minimum of implied costs of unresolved faults being passed over into occupation. This is a way to understand why the assembly of large performance critical systems, such as a rocket, differs markedly from construction. The result of applying optimum fault finding with the constraint of no spill over, results in subsystems at every stage being tested and commissioned. The whole design process of requirements decomposition is constructed to support this.

In the fault finding interpretation, measuring and setting flow rates becomes correcting the fault of an initially incorrect rate of flow setting that is expected to occur with certainty for components off the shelf. We introduce this pedagogical manoeuvre to give a more strategic content to the commissioning plan. It is now not just a sequence dictated by the engineering logic of the installed plant, but by an effort to clear hard-to-solve faults early. The strategy works within a framework of probabilities of

problems. Thus there was no need to plan to disassemble a pump to test its components while there is a high probability that that pumps delivered from a manufacturer with a good QA system will work.

3. Strategic Planning for Fault Finding

There are algorithms to assist in the design of fault finding though to our knowledge these have not been used to supplement a commissioning engineers experience in building services. Fault finding algorithms have been reviewed more widely (4). It is outside of the scope of this paper to explore these algorithms in detail. Though a sketch might be useful.

The algorithms are based on a graphical model of the system where each node represents a stage in a process to deliver an output. When a fault occurs at one or more of the nodes an output fails. The algorithm then calculates the test schedule most likely to reach the fault in the fastest time. This reflects the probability of failure of different components and possibly clues from the simultaneous failure of several processes. A conventional fault finding algorithm seeks to minimise the steps to find the fault. Here we would attach a weighting to each fault indicating how long it would take to service. This is likely to result in the algorithm sorting the ‘designed to fail’ steps of the conventional commissioning process pushing the hard to repair as deep back into the construction project as possible. Commissioning engineers no doubt already do some of this by experience, but as projects get more complex algorithmic support should be welcome.

Construction uses variations of what is sometimes called the ‘waterfall’ (as in the RIBA Plan of Work (5)) where design and fabrication takes place in sequential steps. The implication is that the project is not tested as a system until it is finally assembled. This is a defensible strategy for projects scalable from past projects or prototypes since successful function has been demonstrated. It is in essence ‘plug-and-play’. This method can be wasteful when there is a degree of novelty in the design so that past success of related structures is not a guarantee of success here.

In engineering sectors where the final performance must meet specification (e.g. as in launching a rocket), ‘waterfall’ programmes would lead to a very inefficient process. As a consequence in methods like the V-system, fault finding is pressed back to the very earliest stage of assembling components off the shelf. Further each subassembly is tested against its own specification before being integrated into the next layer of assembly which itself is then tested. This has the advantage that if a specification fails, it is rapidly located as occurring at the last level of systems integration. To facilitate the V-method, the design itself is heavily modularised. Functional decomposition is undertaken through successive layers of the design and it is this decomposition that is the basis for testing each subassembly. This might be viewed as a form of ‘design for commissioning’.

4. Design for Commissioning

Now in addressing wider issues of build-ability of complex buildings, it has become common to supplement the waterfall process by adding contractor insights to the design process, such as in AIA's Integrated Project Delivery (6). Design for commissioning has a similar focus on the practicality of realising the design. Who undertakes commissioning differs with national contractual structures. In many US buildings, the commissioning engineer is directly responsible to the client, and in effect affirms that the building is ready for handover and final payments to the contractor. In Europe, the contractor takes responsibility for the state of the building and so employs the commissioning subcontractor. This implies that there will be differing incentives to reflect commissioning requirements in the design.

Some of the most basic requirements for design for commissioning are:

1. Accessibility of measuring equipment and regulating stations
2. Avoidance of high pressure drops across dampers or terminal unit valves
3. Regulating valves having good authority over flow in the circuit
4. Sufficient straight run to avoid turbulence at measuring points

None of these can be realistically corrected by the time commissioning is begun against a tight timescale. Requirement (1) may fail through no fault of the system designer or installer, but work by subsequent subcontractors. Requirement (4) can fail because, when the pipework is installed, other fixtures prevent a straight pipe run. A BIM may be at too high a level of abstraction to catch such minor clashes and in any BIM case states what should be built, not what was actually built.

Interviews with commissioning engineers by one of the authors (Noye) suggests there is often a phase where commissioning specialists comment on the design for commission-ability, but the commissioning manager's feedback seems to be rarely taken into account. One of the explanations given was that the designer and the project manager do not understand commissioning and do not give it enough importance in finalising the design.

5. Extending Design for Manufacture and Assembly

A logical extension of integrated design is Design for Manufacture and Assembly (DFMA). DFMA is already extensively used in manufacturing industry (7). This philosophy deployed in construction, recognises that for many complex building projects taking place on crowded premium city sites, the only viable means of construction involves substantial offsite construction. This necessarily imposes some degree of modularisation on the design, but this is a small price to pay for much higher build quality and assured build-ability. DFMA is most often applied to the structural components. However it has become increasingly common to prefabricate

part of plant rooms and deliver these on site. The Leadenhall Building (Figure 1), a 224 metre high commercial building in the City of London, took the prefabrication of services one step further.



Fig. 1 Leadenhall Building under construction

In the Leadenhall Building Crown House technologies utilised Laing O'Rourke's Design for Manufacture & Assembly strategy. The major elements of the building's services were manufactured off site at the Laing O'Rourke factory in the West Midlands. This included not just the structural components of the service core, but also modular plant and control rooms as well as a significant number of riser assemblies. Once completed and delivered to site, CHt expert teams led their assembly and final commissioning.



Fig. 2 Pump Skid Module for easy assembly offsite

With its busy inner city location and the structure's site footprint having no lay-down areas, a key challenge for CHt was to develop an offsite approach. Particular consideration was given at the design development / technical design stages with regard to the logistics element, so that the modules would be designed in relation to maximum transportation limitations, onsite access and our lifting strategy, so that a seamless process was in place to support the construction schedule.

Digital engineering proved essential to interrogate the design to a high level of detail in conjunction with the client and design teams. This improved the understanding of the ambitious structure and built in flexibility to adjust the permanent works design. Site logistics were digitally coordinated with overnight deliveries scheduled to reduce disturbance and traffic.

The main plant is situated within the basement and attic levels, which includes central chilled water plant and fully packaged cooling towers, HV standby generation consisting of four sets situated at levels 47 and 48 and boilers c/w gas booster sets. The programme was reduced as the high level on floor service installation and services within the risers were then fully modularised and delivered and installed with the steel frame of the building. On-floor plant rooms were completed and tested offsite prior to delivery (Figure 2), then dropped into position for module connection. All this then helped reduce risk during on-site commissioning and ensured a high quality snag free installation.

6. Design For Data

DFMA seems able to handle all the design for pre-commissioning requirements. It is therefore a pointer to other design and fabrication approaches. It cannot address the more fundamental uncertainties (1) – (3). While the modularisation in DFMA can make it possible to commission a large building in stages, it is seldom possible to occupy a partially completed building safely. The final integration of systems (e.g. lift, fire etc) may still produce problems that eat into commissioning time. It therefore seems inevitable that some fault monitoring capability will be required that extends beyond handover.

This could in theory be provided by the Building Management System (BMS), but as the authors have previously argued (8), a BMS is seldom fit for this purpose. The BMS is brought on line relatively late and indeed the well-commissioned building is sometimes used to check the function of the BMS! It is designed largely for exception monitoring and signalling a problem not diagnosing it. While ‘Design for Commissioning’ might be tempted to expand the role of the BMS, it is neither economically practical nor ergonomically smart to smother the building with sensors on the off chance they might be needed to analyse an anomaly in the period immediately after hand over.

It is far better for the design to envisage a handover portable monitoring system (e.g. Pop-Up Monitoring as described in (8)) to have at hand a system to cluster forensic tests around problem areas or components. It would therefore seem that coupling DFMA techniques with optimised commissioning strategies and post-occupancy forensic capability is the way forward to convincingly close the performance gap.

7. Conclusion

We have argued that commissioning is a vital, but often neglected part of the construction process, and that incomplete commissioning will contribute to the design performance gap. Commissioning was seen to be a form of more general fault finding paradigm, and that optimising fault finding forensics so that they could be completed with the minimum disruption to handover, led to reconfiguration of elements of the design process. DFMA provides an excellent vehicle for this reconfiguration because it provides opportunities to commission offsite and test in a modular fashion. It cannot address performance problems that result from design assumptions that proved false. Economics dictates against expanding the BMS to cover every possible eventuality, but design can envisage deployment of new portable monitoring systems. Together these approaches should have a significant impact on final performance.

Acknowledgment

This work was funded by Laing O'Rourke at the Laing O'Rourke Centre for Systems Engineering and Innovation.

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