Quality Management and Digitalization for Building Performance

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Quality Management and digitalization are two equally booming terms when it comes to building performance. And since the EU has decided to further promote building automation as an essential part of buildings with EPBD from 2025* on, the importance of both will most likely further increase. And for a good reason: both are urgently needed if we want to improve the energy efficiency of our building stock.

A tale of sustainability: To achieve a Gold-level certification, a building owner integrates energy efficient supply systems in his building like a CHP, a heat pump, a solar thermal collector and an absorption chiller. The low calculated energy demand grants additional credits for certification. Shortly after handover, he notices that some of the systems don't seem to work the way they should. It turns out that the management of the different systems is quite a challenge and had never really been specified in the design phase. Some systems can't even communicate with each other. After months of claim management and frustrating attempts to find out how the *system-as-a-whole* should work, the operation staff decided to keep the heating and cooling valves in a large air handling unit constantly open to create constant energy demand. The systems now run smoothly due to the continuous consumption of heating and cooling energy at the same time. And the owner lived disillusioned ever after.

Building performance

The case on the left below could be a joke, but unfortunately it is not. Furthermore, it is representing a common scenario where a lot of participants with good intentions don't have the understanding of the technical complexity of a modern building. In this article we try to outline some of the tools we can use to support proactive quality management instead of reactive quality assurance or even worse need for improvement as a result of the construction that does not meet the requirements of the owner.

Europeans spend more than 90% of their lifetime in the buildings. Therefore, indoor environment should be a priority for a design and operation. Since buildings also cause 35% of all CO_2-emissions, energy efficiency is no less important either. As a consequence, Europe has taken important steps towards better buildings. Today, innovative technologies allow high performance and nearly zero energy buildings providing excellent IEQ. Moreover, over the last years, ambitious building codes have been continuously asking for higher standards and lower energy consumption. As a result, energy consumption in operation of the new buildings has decreased – at least in some types of building and systems. At the same time a phenomenon has become evident: those new buildings with their ventilation and automation systems turn out to be rather complicated technical systems apparently being a huge challenge to designers, engineers, construction companies and facilities manager – and even to owners and users. As a consequence, the performance gap appeared: buildings do not work as intended. They miss their initial performance targets in operation. This is doubly costly: first the design and construction cause additional cost and then, later, operation cost are also higher than expected. This is an economic and ecologic no-go.

Solutions to this problem can be found in other industries: quality management. The term "Quality" is a colloquially often used to refer do a characteristic of an object or generally something "good". In engineering, "quality" describes the degree, to which a set of inherent characteristics of an object fulfills requirements. Consequently, "quality management" is a process of supporting the fulfillment of requirements. Since today building suffers greatly from a performance gap, the bottom line is that we have a deficit in quality management for building performance.

* DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

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In 2012 a new 6,000 m² domicile was handed over from the design-build contractor to the owner. Various Danish media described the construction process as a success and all parties were satisfied with the result. The designers were particularly satisfied with the technical solutions:

- "Everything was tested before the building was put to service"
- The building achieved an architectural prize

Despite the fine words from all the dignitaries the employees working in the building kept complaining about the indoor climate. After the design professionals have tried to map the reason for the complains and after them the client advisor, a skilled Cx-team was invited to verify the indoor Climate. At this time, it is four years after hand-over.

The Cx team did the following observations and measurements:

- Unhealthy air
- Very varying air velocities in the working areas
- Too little supply of fresh air
- Poor distribution of the fresh air supplied from ventilation system
- Rapid rise of temperatures when the sun hits the facade

The ventilation system is designed as a Constant Air Volume system (CAV) despite meeting rooms operate with Variable Air Volume (VAV)

> Pressure oscillates in the air distribution ducts, the system can't obtain the values in the balancing report

No measuring points on hydronic systems

> Hydronic balancing is not possible

The story continues:
Ventilation system extracts air above ceiling without distribution ducts and Chill Beams are installed without following the requirements of the producer

> Draft

Architectural solution with windows in aluminum cassettes bolted to the outside of the facade

> Temperatures in the Cassettes up to 72°C, inner surface temperature measured on the glass 35–40°C

- Radiators are heating, also in the summer
- Solar screens operate after a control sequence that is not described
- The whole cooling system is running constantly – also in the winter – to keep IT-installations cold

Conclusion

- The owner's indoor climate requirements are not met
- Indoor conditions are so bad that it is not allowed to have employees working in the building
- 50% dissatisfied employees
- Energy consumption out of control
- Costly renewal of all technical installations and new cooling and ventilation concept necessitating new installations above ceilings and new ceiling system to be implemented while the building is in use

The Performance Gap

What is the performance gap that we aim to eliminate with quality management? It is often seen as energy consumption higher than budgeted. But energy is still cheap and for owners it is often much more serious if for example the indoor climate is negatively affecting the productivity of the employees. As you can read in the case above, the performance gap is a complex thing both to map and to handle. PhD student Helle Lohmann Rasmussen from Center for Facilities Management, DTU Management Engineering, Technical University of Denmark, has mapped various types of performance gap [1] in **Figure 1**.

Figure 1. Figure A Facilities Manager's typology of performance gaps.

The complexity of buildings and the variety of causes for the performance gap indicate the challenge to implement an effective quality management.

Quality Management

Somehow, quality management is of course a part of any building. Construction needs verifiable calculations for their statics that are engineered and cross-checked, concepts for fire protection need to be defined in early design stages and should be tested before handover and every elevator is frequently being inspected. Usually, these tests are being carried out by a third party along well-defined testing procedures usually by technical experts for the very field.

Building performance as a whole though is not covered by an effective quality management process. In fact, well-defined third-party testing is often only applied in the still very rare buildings undergoing a certification process for sustainability, e.g. DGNB, HQE, BREEAM or LEED. They give credits for the application of certain quality management procedures.

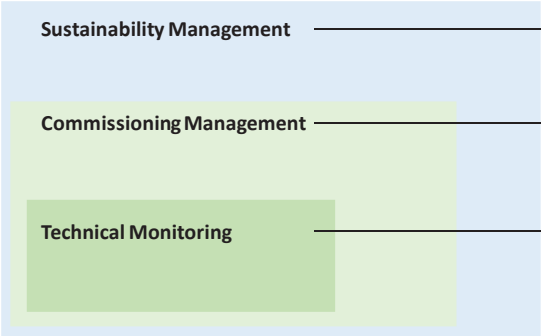


Figure 2. Quality management services as part of certification schemes.

Two of these procedures have evolved as particularly reliable and valuable services – even independently form certification schemes – and they are becoming increasingly popular: Technical Monitoring and Commissioning.

As a core aspect, both services have in common that they should be provided by an independent third-party that is explicitly not responsible for the design, construction and operation of the building. This independence is a prerequisite for the effective service and a transparent communication of any deficit detected by the quality management procedures.

Technical Monitoring (TMon)**

Technical Monitoring follows very closely the principal concept of quality by testing the fulfillment of requirements and thereby establishing a quality control loop for building performance. The service focusses on the precise definition of requirements as the basis for quality management and the application of testing procedures for those requirements.

The quality control loop as defined for technical monitoring consists of four essential elements listed in **Table 1**.

Table 1. Phases of the quality control loop for technical monitoring.

Target values define measurable requirements for buildings and its systems. This may include the maximum level of CO_2-concentration in a conference room, the coefficient of performance of a chiller plant or the set point of a supply air temperature of an air handling unit at a certain ambient air temperature.
Measured values are the values obtained from building or system operation. The building has to be technically able to provide this data, e.g. via its building management system or additional metering devices. They need to precisely correspond to the target values.
Evaluation procedures. To be able to check whether a building fulfills its requirements, TMon applies evaluation procedures to compare the measured values versus the target values. Here it becomes apparent that both need to be defined very carefully to allow a meaningful evaluation: If one uses for example the overall energy consumption of a building as a target value, this value will be very uncertain due to assumptions in design as well as through the actual use of the building that is affected by – among others – tenants moving in step by step, changes in use and user behavior.
Actions. To actually improve building performance, TMon needs to communicate its findings effectively into the project. Any evaluation therefore needs to provide reliable and transparent results that can be delivered to engineers, contractors and maintenance personnel in time to be recognized and to allow appropriate response.

** The service is described e.g. by AMEV 135, VDI 6041 and also within the LEED certification as monitoring-based commissioning.

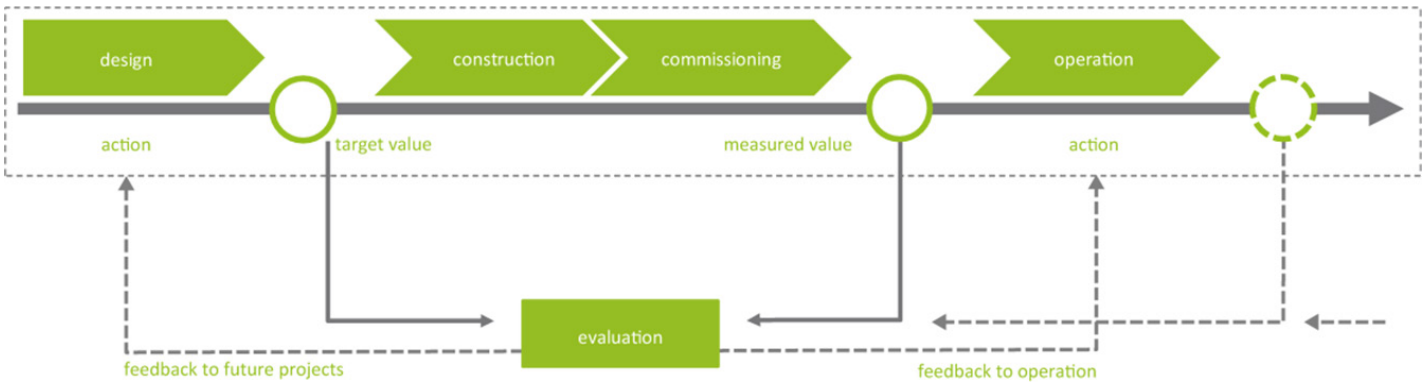


Figure 3. Quality Control loop.

If these four elements are implemented well into a building project, usually starting with the definition of "testable" requirements in the design phase, TMon can deliver a timely and very cost-effective support for any building project. In addition to the immediate control loop within a project, TMon also sets up a long tail loop: It allows to derive reliable experiences to learn for future projects.

Since TMon is based upon individual functional target values, it can be applied with an individually defined scope e.g. on individual systems and values. The option to choose an appropriate scope supports the cost effectiveness of the service.

Commissioning (Cx)

When we talk about Commissioning, we talk about a process. Commissioning is often misunderstood as "testing in the end". The direct translation of the English word has led to many misunderstandings. It is therefore essential that we distinguish between the "event of commissioning" which means "starting up" and the "Commissioning Process" that consists of a sequence of activities spread throughout the construction process, from the pre-design phase to at least one year into operation.

Many building owners are asking "Why do I have to pay for Commissioning, has it not been included since the beginning of time?" The simple answer to that is: "Yes, the event of Commissioning has always been included, and it might also have been sufficient before, but with the complexity of today's buildings, you have to do something extra".

In **Figure 4** it is illustrated that faults, misunderstandings and demand for clarifications occur through the whole construction project and not only in the construction phase.

The Commissioning process starts in the pre-design phase and formally ends one year after completion. It does not take over any of the activities, that the designers and the contractors are already hired to do; they still have to manage the quality of their own delivery and balance their own installations.

Commissioning (Cx) follows a broader scope than TMon. In addition to the "pure" specification and testing within Technical Monitoring, Cx includes a variety of additional services ranging from checking the of design documents, operationability, for example the accessibility of air handling units for maintenance services to functional testing of systems (Life-cycle cost calculations are good tools for that), O&M documentation and supervision of building maintenance personnel training.

The Commissioning Process can be illustrated in a simplified manner as shown in **Figure 5**.

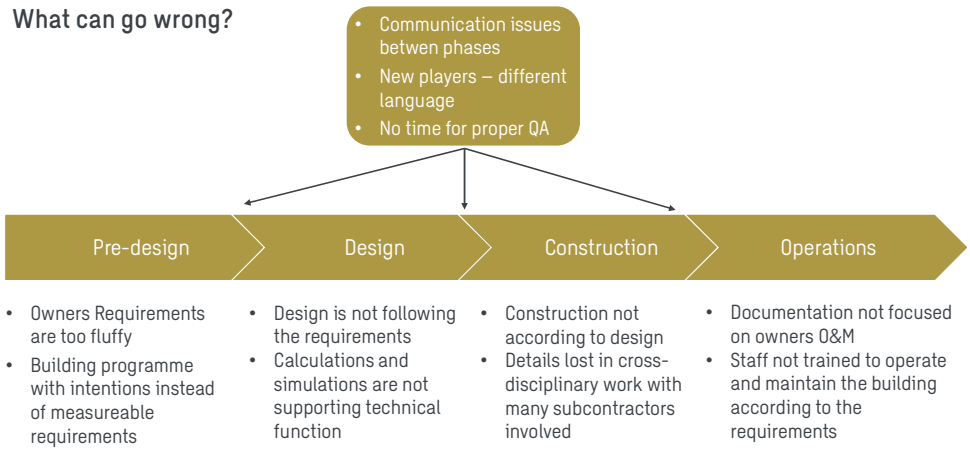


Figure 4. Possible causes of mistakes throughout the construction process.

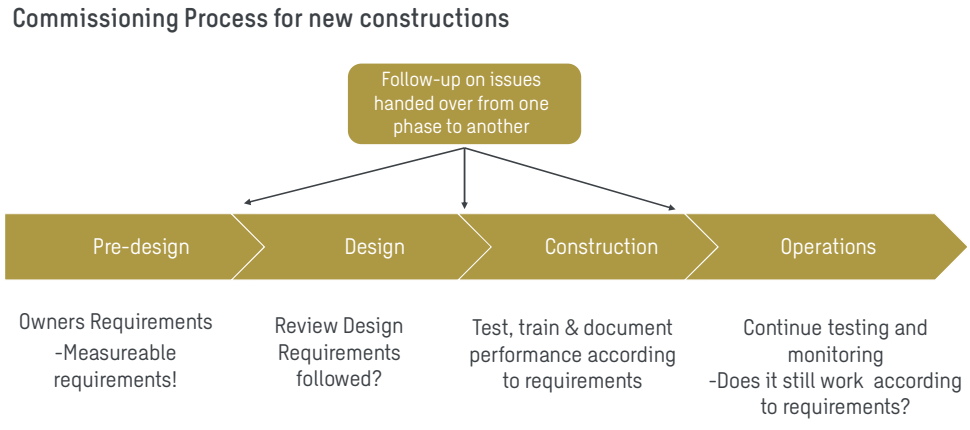
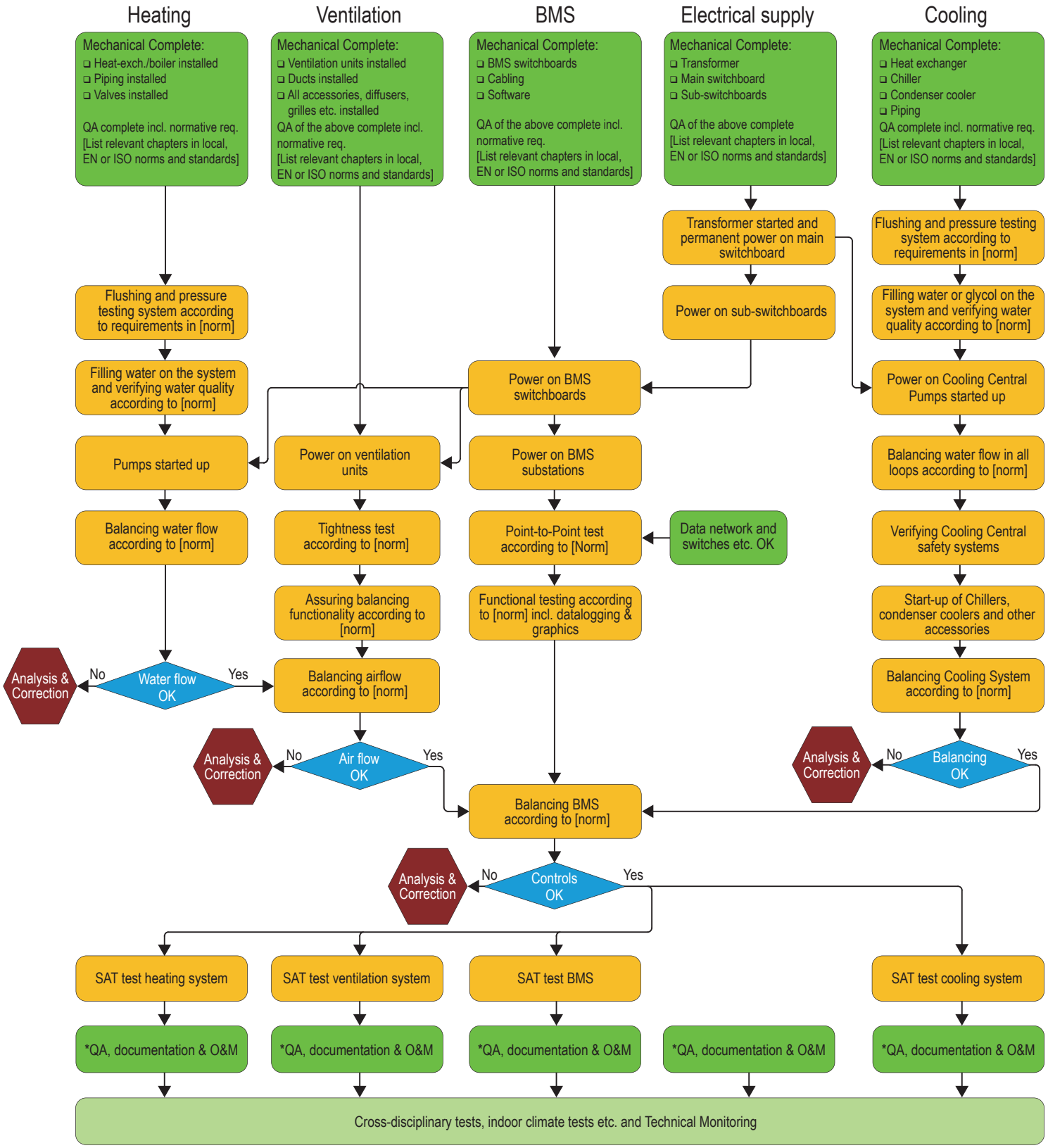


Figure 5. The Commissioning process made simple.

Flowchart interdependence between deliveries for typical HVAC start-up, balancing and verification



Prerequisite. Dark green boxes contains prerequisites. Documentation for fulfilled prerequisite must be shown.

Contractor Action. Yellow boxes are actions with an accompanying document reporting the action.

Acceptance. Blue diamonds show acceptance by the CxP.

Issue. Red hexagons for issues to solve.

Commissioning Action. Light green boxes are Cx or TM actions with an accompanying document reporting the action.

[Text in square brackets] refers to the corresponding norm. Local domestic norms must be activated, preferably related to EN, ISO or other international documents.

***QA, documentation & O&M**. All QA is completed. All issues solved and accepted by the commissioning provider. Documentation, drawings and descriptions exists. O&M exists.

Figure 6. Pre-required data for technical monitoring and commissioning. [© Ole Teisen 2018, Sweco A/S]

The complete Commissioning Process typically consists of a facilitation of the owner to set up measurable requirements for the process, minimum of two operations-focused cross-disciplinary design reviews, sample performance testing of systems and indoor climate, planning of digital hand-over of O&M and documentation and planning of user training. In the operations phase the Commissioning Process continues as "On-going Commissioning" or "Monitoring-Based Commissioning". Technical Monitoring should always be included as a core service of Commissioning.

In a popular way one could say that the Commissioning Process contains all quality management activities needed to facilitate and pass the tests of the Technical Monitoring.

To illustrate the complex relations and connections within modern buildings, **Figure 6** shows some of the prerequisites for TMon an Commissioning tests. It is very useful to include the tracking of all these QA documents listed here in the Commissioning Process to facilitate that systems are completed and quality assured before they participate in a cross-disciplinary test.

What is it worth?

The potential of a better quality as well as of TMon and Cx has been shown in numerous studies. For Technical Monitoring, that since 2017 in some German states is mandatory for public buildings, a study at Technische Universität Braunschweig [2] showed a return on invest of less than one year for Technical Monitoring. These numbers have been confirmed by about 250 TMon projects on more than 3,000 systems we did at synavision with our Digital Test Bench.

On commissioning, Evan Mills has analyzed 399 Commissioning projects, 322 on existing buildings and 22 on new constructions [3]. He found that the pay-back time for investment in a Commissioning Process that was 4.2 years for new constructions and 1.1 years for existing buildings. In the same study is found that the Commissioning Process costs ½–1% of construction costs. The study is renewed in the end of 2018. The own experience in Sweco is that pay-back time for new constructions are much lower than in the US. All the Commissioning projects the company has managed have paid back before hand-over in found deficiencies that would have been costly to redo later. Deficiencies are rooted in all stages of the construction process, and if they are found when testing and monitoring the completed construction, they usually are costly to fix. This can be illustrated by the curves in **Figure 7**.

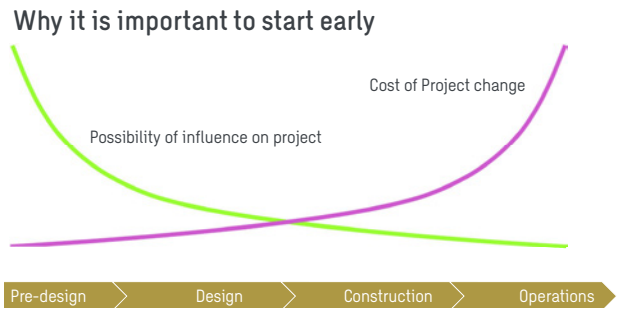


Figure 7. Deficiencies found when testing and monitoring the completed construction are usually costly to fix.

Digitalization

In the Commissioning Process, the hand-over of O&M documentation (and drawings calculations, descriptions etc.) is usually handled through a digital tool. The typical and well-proven option is to enter all data related to O&M, QM, Balancing Reports, documentation, design and drawings together with the documents of the Commissioning Process in the owners CMMS (Computerized Maintenance Management System) system that then serves as the "Systems Manual" hosting everv related documentation.

In Sweco we have now projects, where we link the Systems Manual (CMMS) and the building model. That opens up for help to find the precise location of a specific maintenance task generated in the system. You can also find the documentation for specific components and be guided into the building model to see in what locations the component is placed.

This linking between the Systems Manual and the Building Model is not very common yet, and we still need to see, if owners in the future will route sufficient resources to the FM staff to assure the maintaining and continuous update of the model and the link to the Systems Manual. But the digital approach is essential for quality management.

Although quality management services are principally available, there are barriers for their success. This became obvious through another quality management process: energy inspections for air conditioning system as required by EPBD. These inspections are mandatory in Germany since 2007 for every system with a cooling power of 12 kWth or more. The number of systems that have to be inspected is estimated to be about 250,000 [4]. So far not more than 10% of these systems actually have been inspected.

Buildings are becoming technically sophisticated systems. Therefore, as in other industries, **quality management** becomes an increasingly important part of the building process. Due to the complexity and uniqueness of buildings, **digitalization** – generally speaking the transformation of manual, human actions into data driven software-based processes – is a prerequisite to facility quality management. The first steps of this transformation started years ago when architects and engineers started to use computer aided design tools instead of pencils to create plans. Now the electronic design is to be further transformed into a digital building information model (BIM) containing information far beyond the physical shape of the construction like time of construction, product information and even ongoing metering data.

The reasons may be various: lack of owners' interest, lack of knowledge about the inspection duty, lack of control by authorities. But one reason is evident: The inspections usually require experienced experts to go on site and test the systems. These engineers simply do not exist! There is already a lack of engineers in the building industry so that additional services, if they are not exceptionally well paid, will have difficulties to succeed. Therefore, digitalization is an important opportunity for building performance. Not so much to cut cost but to enable quality management at all.

In this regard, TMon is of particular interest since the quality loop of defining target values, collecting measured data, evaluation it and communicating it to the project can be transformed completely into a digital service. One example is our Digital Test Bench at Synavision, which is currently proving its effectiveness within the EU funded Horizon 2020 project QUANTUM (www.quantum-project.eu). Our software as a service offers tools to digitally specify target values, import and evaluate data and produce a precise and transparent feedback. The software can be applied in new construction with a focus on the startup phase or in existing buildings e.g. for digital energy inspections. Due to the large extend of digitalization, the process does not require significant expert knowledge and in consequence can scale up massively and robustly.

Building performance needs to be improved in Europe. The technologies are already at hand. If we introduce quality management to ensure project success and if we use the new opportunities of digitalization, chances are good to turn the European building stock into a truly sustainable living environment.

Valuable sources of Commissioning Process knowledge

- IEA ECBCS Annex 47
- ASHRAE Guideline 0-2013
- ASHRAE standard 202
- BSRIA "Soft Landings"
- Danish Standard DS 3090
- LEED ver. 4
- DGNB Danish version Criterion 1.7 ■

References

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[2] Stefan Plesser et al. (2018) „GA Spec&Check. Entwicklung und Erprobung einer Methodik zur Beschreibung, Abnahme und Überwachung von Funktionen der Gebäudeautomation", Technische Universität Braunschweig.

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