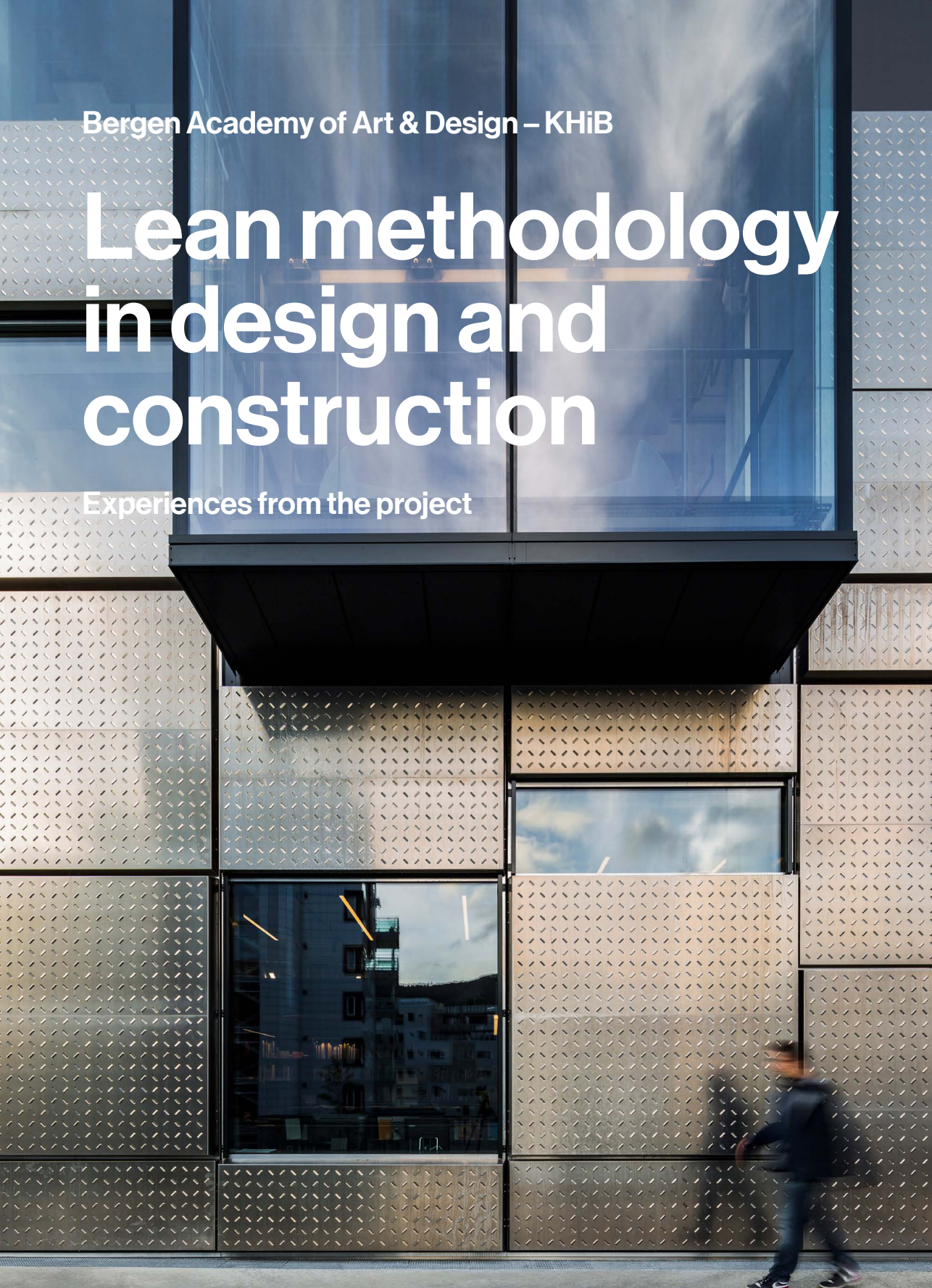


Bergen Academy of Art & Design – KHiB

Lean methodology in design and construction

Experiences from the project



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**«It's madness to do the same
things over and over again
and expect other results.»**

–Albert Einstein

15 years of experience

or...

1 year of experience 15 times?

«Nothing changes if nothing changes.»

**The KHiB project vision:
from reactive to proactive**







Content

Lean methodology in design and construction

The compilation is finished
05th December 2018

From January 1.st. 2017 KHiB has become a faculty of The University of Bergen (UiB) named Faculty of Art, Music, Design (KMD). This booklet has chosen to continue using the name KHiB.

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Introduction



Project introduction

KMD, the new Faculty of Fine Art, Music and Design of the University of Bergen in Norway, opened October 2017 and is designed by internationally acclaimed Norwegian architects Snøhetta.

At 14,800 sqm the faculty is the second largest cultural building in Bergen after the 1,500-seat Grieg Concert Hall. The building occupies a landmark site at Møllendal in Bergen, overlooking the waterfront and surrounded by the seven mountains of Bergen. Replacing the former Bergen Academy of Art & Design (KHiB), which was housed in six different buildings in separate locations around Bergen, KMD is now part of the University of Bergen. The new KMD building gathers the whole school, including both fine art and design departments, under one roof, within the newly formed faculty.

The new building offers exciting opportunities for learning, and cross-fertilization between different practices. The KMD is designed to encourage a new culture of cooperation across disciplines and to explore possibilities for their practice far more widely, not only through the sharing of physical space but as a matter of policy.

The KMD building will also house parts of the administration of the city's distinguished Grieg Academy, which has been the University's Department of Music since 1995. The University is now in the planning phase to deliver a bespoke music building for The Grieg Academy on a neighboring site at Møllendal. Meanwhile, the outdoor spaces and a magnificent project hall within the KMD building will already be shared by the art, music and design departments.

The Bergen Academy of Art and Design and the Grieg Academy are both long established institutions, and are recognized regional leaders in their fields. Now, the newly established KMD confirms the University of Bergen as a formidable international center for education in the arts, at both undergraduate and postgraduate levels.

The KHiB Lean in brief

Lean can mean different things to different people. In order to avoid misunderstandings, it is important to explain and clarify what Lean means to you. The actual word Lean can mean slender, slim, thrifty or even, for example. In the construction industry the term can often mean a mix of continuous improvement, removal of waste, value creation, and focus on process and flow. It can vary according to context, design phase, and the individual company.

The KHiB project has placed particular emphasis on Lean for the involved parties entailing flow, process, the bigger picture, proactivity, transparency with visualisation, and use of BIM. (BIM = Building Information Modelling, see also separate chapter)

The ideas behind, and theory of, Lean are not elaborated on, because there is already a great deal of literature on this field. The booklet is one of five produced by the KHiB project. The other booklets deal with Lean strategy, BIM, systematic completion, and Lean construction. Together, they provide a good overview of what the project has achieved and the lessons we have learned.

For most of those involved, the KHiB-project has been the first encounter with a systematic way of working with Lean. This means that time was also made available to experiment and fail.



The purpose of this compilation

Lean construction and takt planning have with time become relatively known within the construction industry. Especially thanks to the Last Planner System. A lot of knowledge and literature about Lean in general and about Lean construction in particular already exists. Due to this, Lean theory and background will not be explained in any more detail.

Throughout both the design and construction stages, the objective of the KHiB project was to work extensively with Lean principles, Lean mentality, and Lean methods. We developed «our own» methodology to be able to work more smartly and correctly with the extensive planning work. It was named Lean Process Planning (also known as Milestone Planning) and Lean Design. This mindset may in many respects be considered as pioneering work.

The KHiB project further developed the highly important process Systematic Completion, which is a structured continuous test procedure of all the systems and functions. This work has to be initialized much earlier than traditionally normal, and it is in the end expected to lead to a successful and error free delivery of the construction.

The methods developed in the project are still in their early stages for the industry. The KHiB project therefore wrote a total of five booklets. These booklets were finalized at various stages throughout the project, and they were not topically chronological. The booklets describe the following topics: Lean Construction, Systematic Completion, Lean Strategy, Lean Design, and BIM@KHiB. Each booklet gives a good overview of its topic, what was done, experiences, and lessons learned.

In this book all five booklets have been compiled and organized logically. With exception of the initial and final sections from each booklet respectively, they have been compiled relatively unchanged. Due to this some overlap is to be expected when reading the text.

The intention of this book is to give a good overview over what has been done in the project and how. The team also wants to tell others about their experiences and lessons learned, and to document how the KHiB project collectively worked with Lean, Systematic Completion, and BIM. Subsequently we hope to contribute to an improving industry.

The time span of the detailed design and construction stages in the KHiB project lasted from August 2013 until May 2017.

Photo: Snøhetta
Stephen Citrone

Some general recommendations when introducing Lean

The recommendations are also supported in Lean literature and by Lean presenters.

- The Lean culture must be supported by the management of the company, “top-down” management. Preferably, management should also be directly involved. (As opposed to a situation in which Lean is being promoted by a few enthusiasts, “bottom up”.) Executive-managed Lean culture can also apply to a larger project, although the lasting effects disappear more quickly when the project is eventually concluded and the resources spread out on different projects.
- It is necessary to have long-term goals and strategic plans for involvement, training, and structural changes. A Lean cultural change takes time! You can easily start with a few projects and then gradually increase the scope over time, e.g. 1-5-15-many.
- Exchanging and sharing experiences with external projects in other companies provides a good insight into how others work with the same principles. We learn from each other, make contacts, and can avoid repeating errors.
- A project or a company should run Lean development in-house, but to continuously receive follow-up guidance and training from specialists/consultants is generally money well spent.
- Tools that support Lean are not the first thing that should be emphasised during a serious introduction of Lean to a project or a company. Introducing Lean only via the use of tools will often, but not always, lead to failure. (It is like beginning to use Excel without having any knowledge of mathematics.)

The main point with Lean implementation is to start from a perspective that you are comfortable with yourself. Start with the Lean mindset, methods, and principles, regardless of contract type, project type, project scope, or company. Then gain experience and develop further. Find your way of doing it.

Everything is connected

It has been demonstrated time and time again that everything is connected. Working in a “silo” is more counter-productive than productive. All involved parties must frequently work and communicate across specialist and company environments. To provide a wider target group with information, it is advantageous that overviews and plans are visualised on easily accessible large boards, whiteboards, smartboards, posters, etc. Transparency promotes trust, an overview, the bigger picture, support between all the involved parties, and creates a belonging to the project.

Bullet points indicating that all things are connected:

- Lean Strategy
- Process Planning
- Reverse Planning
- Lean Design
- Takt Planning
- Function and Geometry in Takt
- Systematic Completion
- Early involvement by contractors and their subcontractors and suppliers
- BIM and Digital Tools

Early involvement of subcontractors (UE) and suppliers (LEV) cannot be emphasised strongly enough. Too often it is demonstrated that the contracting parties (seen from the client's perspective) think primarily about their own personnel and their own description of the construction. Too often, no consideration has been given to items that have long lead times, are subject to special functional requirements, or require the specific approval of a consultant or architect. As long as the Lean culture is still in its infancy among many companies, the planning and contracting of subcontractors and suppliers must be conducted at an early stage (e.g. with the help and support of the client).

Lean Strategy

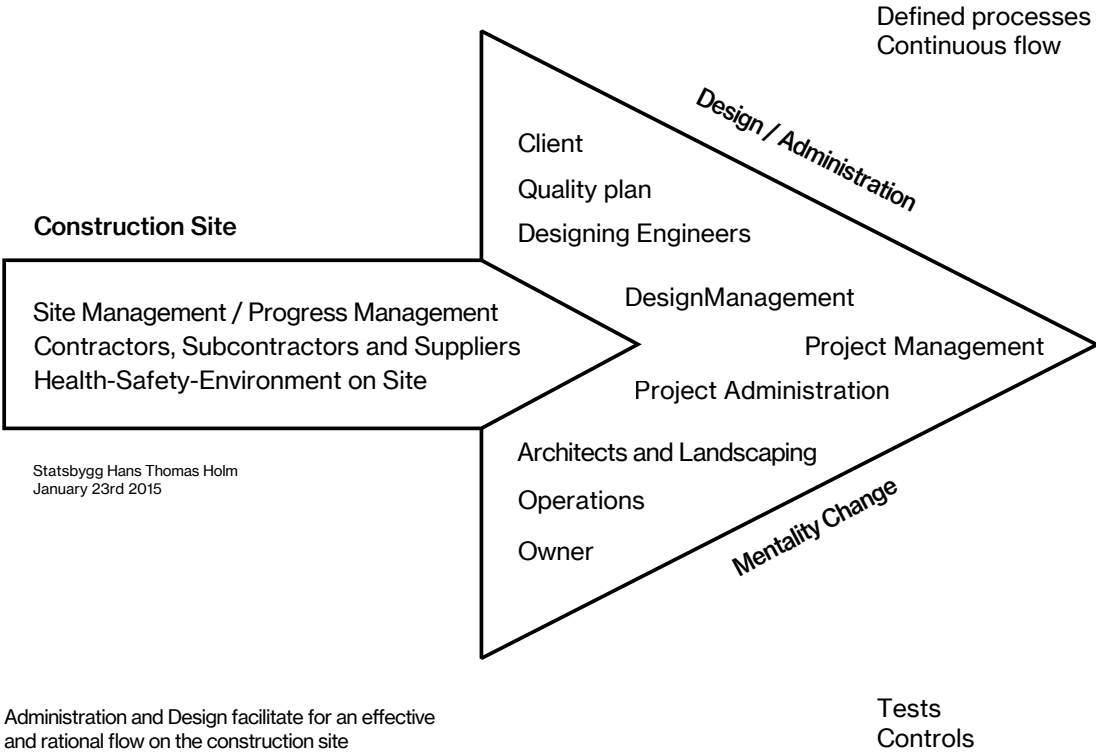
Lean in the KHiB project

Upon allocation of funding for the implementation of the KHiB project in June 2013, it was the intention of project management that the philosophy of Lean methodology and Lean construction should be implemented from the start of the detailed design stage. Lean should permeate the organisation at all levels in order to create a uniform culture. It was important to incorporate the principles of Lean in a strategic plan, in as many fundamental contract documents as possible, in a training plan, and in the ongoing interaction between the construction client's administration, engineering design personnel, and executing parties. As this had not been accomplished in a correspondingly systematic and structured way previously, the project has attempted to identify its own way of implementing this. (For the majority of people involved, KHiB is the first structured encounter with Lean. Consequently, it was not expected that everything would go according to plan.)

KHiB vision: from reactive to proactive

The KHiB project has particularly emphasised creating and maintaining a Lean culture and Lean attitudes. The project has not prioritised KPIs (Key Performance Indicators, i.e. measurements) or tools. By staying well abreast with the planning, the objective has been to make everyone involved more proactive rather than reactive. It transpires that this change is easier said than done, but that changes are possible.

The project vision has been defined to be: From reactive to proactive. From a figurative perspective, this is illustrated by the administration, project planning department and others “ploughing” away challenges and potential issues so that the construction site run by site management and contractors can achieve the best possible production flow.



Lean interaction memorandum and strategic plan

A fundamental document for the project has been the “Lean interaction memorandum”. Amongst other things, the memorandum describes all project goals, which contract documents require separate clauses about Lean. How Lean should be taught throughout the project, and in which phases the various parts of Lean are to be emphasised, etc. The interaction memorandum was included as a general legal document in line with the tender documents in all contracts that were awarded, and then became part of the contract documents.

Experience suggests that this document can be described even better and more comprehensively, but also that it has been a really good “recipe” for Lean implementation in the project.

The following illustration shows the order of the strategic implementation of Lean in the KHiB project with the main focus of each sub-phase particularly specified:

- Lean Culture and Mentality
Together creating a strong Lean culture
«The Plough»
- Lean Process Planning
Define, Plan and Think Processes
- Lean Design
Large, unmanagable topics are split in smaller, similar, manageable pieces
Visual Planning / The Bigger Picture / Transparency
- Lean Construction and Logistics
Takt Control Areas / Cross Functional Dependencies / Single Trade Construction sequences
Deliveries «Just-In-Time»
- Tools: BIM and dRofus (a database room function program)

Experience/Learning:

- The interaction memorandum, i.e. the strategic plan, forms a basis for being able to use Lean throughout the entire project and at all levels.
- It is very easy to fall back into old habits. The gravitational pull of the traditional is very strong. Thus, the Lean mindset and culture must be constantly maintained.

Lean elements and The Collaboration model

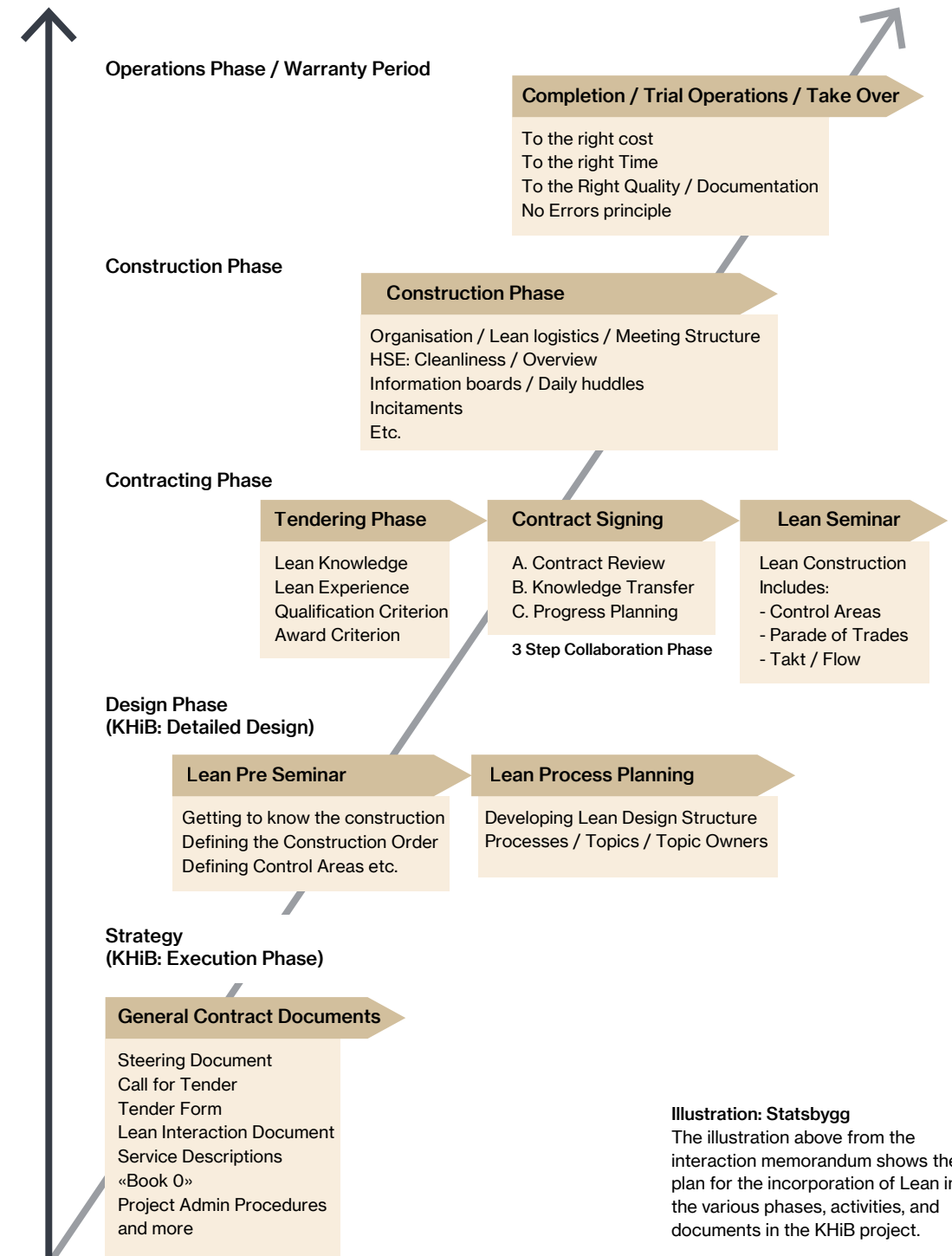


Illustration: Statsbygg
The illustration above from the interaction memorandum shows the plan for the incorporation of Lean in the various phases, activities, and documents in the KHiB project.

Lean implementation: elements used in the KHiB project

General contract documents

In addition to the interaction memorandum, smaller paragraphs about Lean have been written in most of the general contract documents such as the steering document, call for tender, tender form, service descriptions, Statsbygg's "Book 0", and project administration procedures (PA book).

The project included sections of text about Lean in a number of different tender documents, with the most current level of knowledge maturity about Lean. It is natural that these sections of text will be developed and will improve with increased experience of each project implemented with Lean methodology.

Pre-seminar, "reverse planning"

The implementation allocation for the KHiB project was made in June 2013, and at that time, Snøhetta had the best knowledge of the project history. The other participants were new. Rambøll was contracted from the detailed planning stage. Statsbygg's employees and the KHiB users were also new arrivals.

An initial activity to make the entire KHiB team into a team, to think in similar ways, and to make provision for further Lean training, was to conduct a two-day pre-seminar. The main objective of the seminar was to gain an understanding of what "reverse planning" entails. Understanding the order in which a building should be built "reversely" is fundamental to being able to consequently carry out the project and design planning in the correct order.

With the help of laminated A0 plan drawings, small groups discussed and concluded how the building should actually be built. There was one group for each floor of the building, and each group was composed of all involved companies in order to create a dynamic mix.

Experience/Learning

- Understanding what reverse planning entails and that the project has a good idea of how a building should be built until it is ready are crucial. Both to the future planning through the use of processes and in prioritising the activities correctly. Considering both building (geometry) and testing (function).

Creating a joint platform

A project requires a joint platform, a joint "language", and a joint culture when you work with Lean. This particularly applies when the maturity surrounding Lean is still at a low level. (The construction industry still has a long way to go until it reaches "critical mass", i.e. when the Lean culture has become a natural part of the modus operandi and things "run by themselves".)

For the engineers at Rambøll, architects at Snøhetta, and many of Statsbygg's employees, Lean was relatively unknown. In order to create the best possible joint platform in the KHiB project, the Lean journey and detailed design started with a half-day seminar featuring the knowledgeable Niklas Modig. Prior to the seminar, everyone had received his book "This is Lean" to read. Thus, the fundamental concepts and philosophy had been explained in a very motivating way, and the KHiB team were able to talk about Lean without talking across each other.

Experience/Learning:

- A joint platform and a joint "language" in a project, or in a company, are essential for the culture to develop in the desired direction.
- Ownership is crucial. Employees must be involved, engaged, and want to contribute to the development.

Process planning

New to the project (and the construction industry) is the KHiB project's extensive use of processes and process planning. Having established a joint platform, the project started with planning the phase for detailed design and the construction phase. Two whole weeks were spent on the task under the direction of Lean consultants, and the result was the "PCP" map (PCP = Product Creation Process).

It should be admitted that the actual PCP map has been used less than intended in the KHiB project. The experience is that the map should be reworked in terms of the so-called key points, and that it must be used more actively in the next project. The weeks with the PCP map gave all project participants a very

good overall understanding of the phases that were about to commence. Process planning has been a key part of the project, and has therefore been described in more detail in a separate paragraph below.

Qualification and contract award criteria (public procurement)

As a government company, Statsbygg complies with the law on public procurement. This affects the preparation of procurement documents, the criteria for awarding contracts, etc. This is in contrast to private companies, which can procure in whatever manner they find expedient.

Public procurement generally entails bidders having to go through both a qualification round and an award round. As of 2016, the market is not sufficiently mature with regard to Lean skills and experience, although the knowledge is increasing.

The KHiB project chose traditional requirements in the qualification round. To ensure that the winning bidders had Lean skills and experience, all contracts were announced with a 20% weighting on Lean in the award round. This will make it easier for the project to have a joint Lean platform with contractors. Experience suggests that there continues to be a great deal of potential with regard to this criterion.

For future projects it will be important that the evaluation of Lean criteria is made with regard to how a company will implement the assignment, i.e. how Lean principles and methodology will be used in the design phase and/or construction phase. Correct construction at the first attempt will significantly ensure progress, increase quality, improve financial results, and reduce the number of errors and defects.

Experience/Learning:

- It would be advantageous to place a greater emphasis on Lean. To ensure that bidders know their (Lean) discipline, it is also recommended that the weighting is assessed through and amongst other presentations and/or interviews with the personnel being offered.
- It must be ensured that the personnel take part actively during the lifetime of the project.

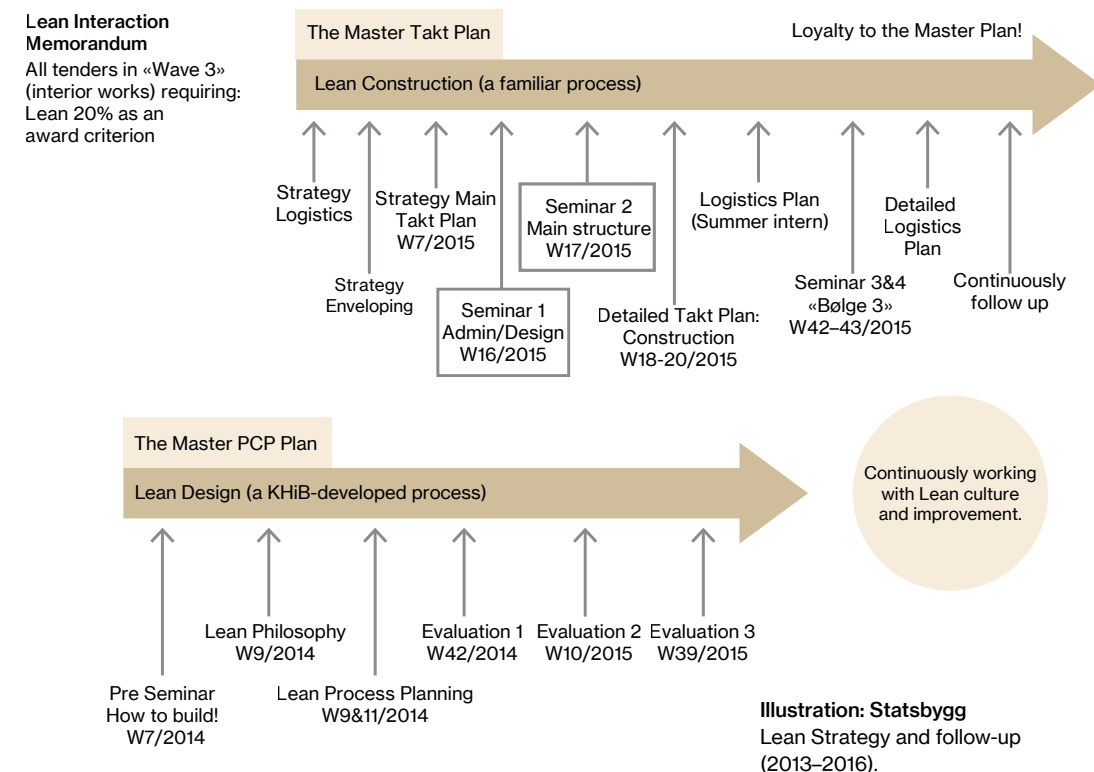
Plan for seminar and training

If a project wants to incorporate a Lean culture and use Lean principles and Lean methodology, it is important that the team has a plan for providing regular training and information updates for the duration of the project. Frequent visits by a Lean adviser, who will ensure that the project gets back on the correct Lean track, is also recommended. An organisation that is unaccustomed to the Lean working philosophy will quickly be drawn towards the traditional pattern of operation. ("Gravitation towards the traditional and habitual is very strong.")

The plan created by the KHiB project comprised primarily the following:

- Training and use of process planning.
- Ongoing evaluations of process thinking.
- Training (seminars) in Lean Takt Time planning (mixed groups of site managers, consultants, and contractors to encourage team spirit).
- Continuous guidance throughout the construction phase.

The plan is shown in the illustration below.



Experience/Learning:

- A strategic plan (“onboarding”) for knowledge enhancement such as continuous training, seminars, courses, etc. is an important contributor and a good aid for maintaining a stable direction in the development of own project or own company.
- Using an external Lean company to help keep the project or company on a stable course is money well spent. Use a consultant with whom you get along with. In any case, the actual “groundwork” must be done by yourself.

Lean Design

Lean Design is described in more detail in a separate chapter. This section will highlight some important principles that have been carried out in the KHiB project.

Engineering design personnel, as well as contractors, have a tendency to work in silos, i.e. mono-disciplinary and resource-efficient, in order to finish as quickly as possible. To avoid the typical problems in project design, the KHiB project has emphasised that the design phase also needs to have a key focus on following the principles of process planning, flow efficiency, and reverse planning. The various disciplines should also maintain frequent and equal work rhythms that serve the construction’s progress in a rational, logical, and proactive way.

The whole design group prepared a natural progress plan based on progress of the construction and systematic completion processes respectively. This entailed that traditional contracts were given a somewhat untraditional content that was more in accordance with the construction.

Also, the design group met frequently, three days every second week, known as collaboration days. Joint visual planning was conducted in order to maintain steady progress in respect of the advisory disciplines, and broad communication took place regarding mono-disciplinary and multi-disciplinary challenges, and which tasks should be prioritised in the upcoming period.

Lean design as implemented in the KHiB project is ground-breaking work and has not been observed previously in other construction projects in Norway.

Experience/Learning:

- By following the principles of process planning, flow effectiveness, and reverse planning in the design phase, it has significantly reduced the number of errors and changes. It has also ensured better implementation of the construction site processes.

- Amongst other things, Lean project planning means that you are already thinking about how the building should be constructed and systematically completed as early as the design phase. Thus, the construction and systematic completion can be implemented in the most optimal way.
- It would be advantageous if construction disciplines and technical disciplines could provide input early in the design phase. It could reduce delays in respect of product input or late process changes.

Quality assurance of design documentation

Lean Design is described in more detail in a separate chapter. However, the important activity of quality assurance of the designed documentation is mentioned here.

The KHiB project used the BIM model to plan progress for the construction period through takt time planning. Over a three-week period, the design material was reviewed by the site managers, the design group, and the project managers. The building was theoretically constructed as a joint effort step by step, something which was enabled with the help of BIM.

The activity made a considerable impact:

- Consultants quality-assured their own material. Many errors and defects were discovered, rectified, and updated on an ongoing basis in this period.
- Site managers were given thorough insight into the description and building and which particular challenges they would face.
- The tender documentation could be submitted together with a detailed progress plan, even if progress had not been finally decided.
- Aspects that required particular focus from suppliers due to issues such as long lead times or complex structures could be listed early and thereby ordered a short time after contracting.

Experience/Learning:

- It is recommended that a review be conducted before tender submission in all projects!
- Consultants must be cross-functionally involved and take ownership of the construction process



Contracting and interaction

- **Contracting:** To ensure knowledge and experience about Lean (or similar), all of the so-called wave 3 contracts had a requirement for 20% Lean as an award criterion. ("Wave 3" is a joint term for the 7 contracts that together constituted the construction activities for all interior finishing works, i.e. in accordance with the closed building milestone.) In several instances the criteria were decisive. In the KHiB project, the 7 contracts were contracted on the same day.
- **Interaction:** The KHiB project chose to implement an extended (construction) process description and takt time planning prior to tender submission, approximately "80%". (See previous section.) This required extensive and constructive co-operation with the contractors on the final and unified takt plan. 3 to 4 months were designated to this work, which was called the interaction phase. (Interaction can be defined and implemented in various ways from project to project.) However, it transpired that the time designated was not sufficient. The correct resources arrived at the construction site only a short time before work was supposed to start, and the content for the interaction meetings could have been better defined.

Experience/Learning:

- In the future, it would be desirable for the evaluation of the award criteria that the resources offered as project responsables are the same people who clarify how Lean principles and methodology will be used in the implementation, i.e. then in the form of a presentation with focus on specified key topics.
- Seen from the client's perspective, the Lean criteria can be given even greater weighting to show the significance of planning, being systematic, and working correctly.
- It is vital that the correct resources are included from the beginning of interaction in order to assess the takt time planning and make it unified. It is in everyone's interest that the takt time plan is predictable and stable throughout the whole construction phase.
- It could be an option to unify many more milestones with collective incentives in the form of multiple bonuses/maluses.

Construction phase and “Super Tuesdays”

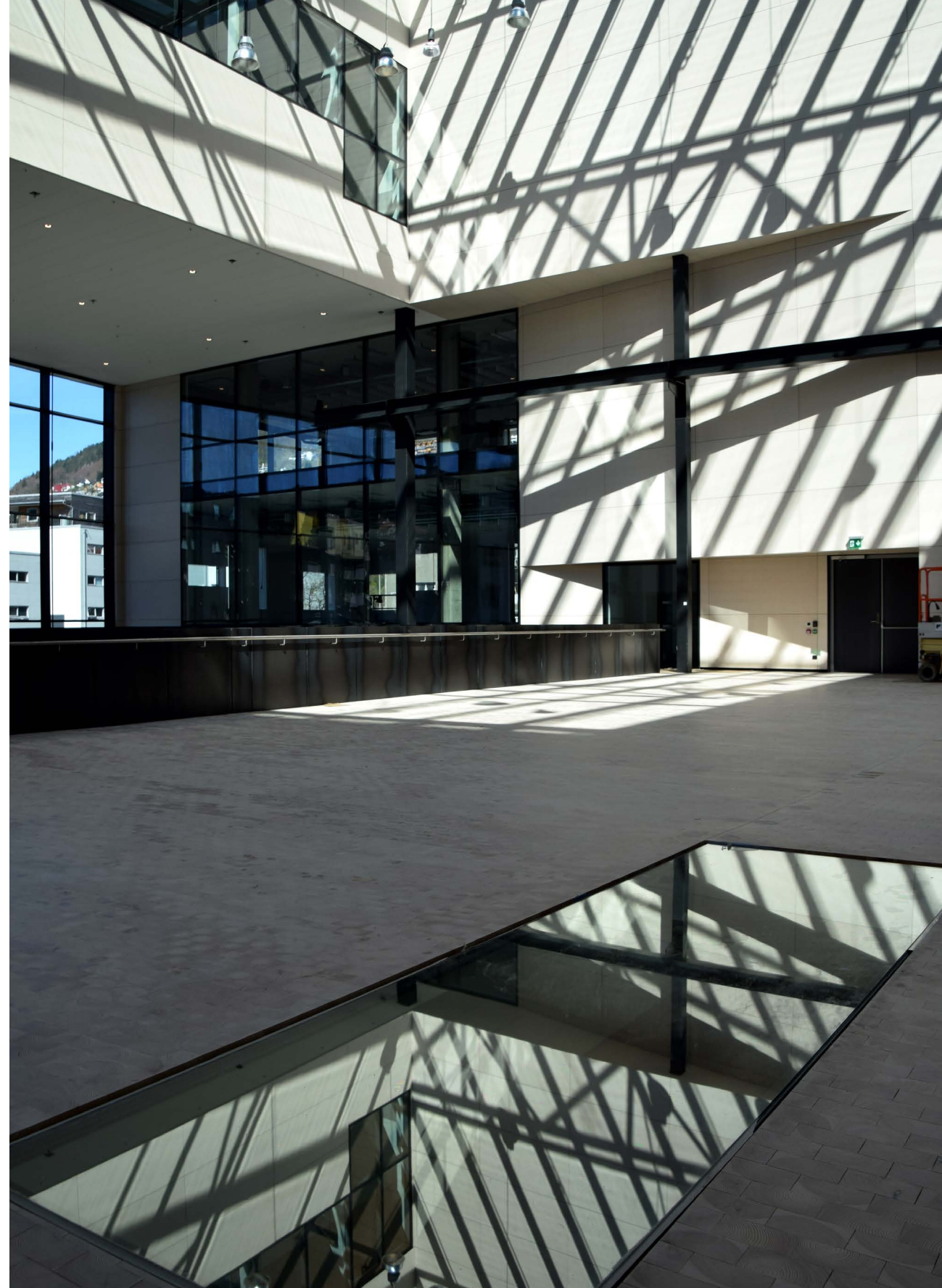
The KHiB project introduced the term “Super Tuesdays”. This was an extension of the fortnightly meetings in the design phase. Every other Tuesday (and also on Wednesdays during the first half of the construction phase) all parties involved would meet, i.e. consultants, contractors, users, operating personnel, site managers, and project managers. They would resolve remaining design issues, pending items, errors, defects, etc. Those responsible for a topic ensured that the necessary resources participated in order to clarify the topic. In this way, it would be possible to get ahead of multiple challenges (including door environments, distribution boards, and the energy centre) and create good contact across all disciplines.

Throughout the construction phase, the takt plan became increasingly more detailed. It was discovered that vertical surfaces had to be planned in as much detail as horizontal surfaces, especially where these areas crossed each other – not least because of HSE issues (Health & Safety). Multi-disciplinary activities and dependencies were detected along the way and could be planned, something which often required an adjustment of the schedule. It is best if all the known conditions and typical challenges can be planned in advance.

Experience/Learning:

- The meeting structure and meeting content will change during the course of the construction phase. Consequently it must be assessed on an ongoing basis how meetings can offer the best value to all parties.
- The involvement of craftsmen is also important, not least to create a sense of Lean ownership at all levels of the organisation.
- It is particularly important to assess and emphasise multi-disciplinary activities, activities with multi-disciplinary dependencies, products/deliveries that have long lead times, and information that the consultants require to complete supplier design planning.
- Lean takt time planning helps raise awareness of multi-disciplinary content and thus makes one leave one’s “silo”.
- Visualise as much as possible on whiteboards or smartboards, something which will promote openness, trust, and accessibility.

Photo: Statsbygg
Hans Thomas Holm





BIM kiosks, Takt boards and a dedicated Site Manager for BIM and digital interaction

The KHiB project has utilised 6 portable BIM kiosks. These were priced into the contractors' specifications. During the construction period, they were particularly used by the technical craftsmen in order to extract measurements, data, and locations, and to be certain of the latest version. (BIM kiosks are in the process of becoming standard equipment on a construction site. Commercial products are already available. Online searches give several hits.)

To train craftsmen in how to use the BIM kiosks and how to navigate in the model in order to procure information, the client had a dedicated site manager for BIM (BL BIM). All craftsmen received training. BL BIM has also followed up on maintenance and updating of the BIM model. Also, BL BIM together with the craftsmen (including foremen) have reviewed the areas due to commence 6, 4, and 1 week before the actual start-up. This is in order to be most optimally prepared for the start. However, these processes can still be practised and improved considerably.

Each control area in the building has had its so-called takt board on which the area's status is reviewed in a daily briefing. Thus, everyone will be up to date with the status of progress at all times, and any measures can be set in motion at short notice.



Experience/Learning:

- The use of BIM kiosks has been entirely positive, and the technical disciplines in particular have used them to a great extent.
- The use of digital tools will considerably increase in the future.
- Takt boards increase the transparency between all disciplines on the construction site, something which is very beneficial to all parties.

Test room, Logistics, and Temporary storage

The KHiB project has emphasised construction and use of a test room. This is in order to permit contractors and site managers to obtain valuable knowledge before construction processes in the building were in full swing, the so-called “trains and carriages”. The test room can also be used as an assessment basis for the client in the event of uncertainty regarding materials, colours, practical solutions, etc. The KHiB project did not take full advantage of the test room, but it is evident that it is a very worthwhile investment for both client and contractors.

The KHiB project has also prioritised having a dedicated logistics manager. There is a very high volume of goods and transport that arrive at a construction site. There is major potential in having the right volumes, at the right time, and in the right location. Also, the various factors for waste can be reduced substantially with proper logistics planning; moving, damage, waiting, losses, etc. As a bonus, a tidy construction site is also achieved as well as increased safety for everyone (HSE). The project experienced minimal noise surrounding logistics and has noted that Lean supply chain management has great potential. The greatest challenges were suppliers and carriers who would still arrive when it suited them best. There must be further discussions about how the industry can act as a keeper for... itself. To simplify logistics planning, particularly for long-distance transports, the KHiB project had the advantage of having large premises for temporary storage next to the construction site. Here, contractors could store and prefabricate smaller components that were to be included in the new building free of charge, something which they greatly benefited from.

The effect of temporary storage for construction sites with small and narrow areas (e.g. urban areas) has great potential and must be developed further.

Experience/Learning:

- The test room should be constructed and fully utilised in construction projects, either by having a separately built test room, or by completing construction of a smaller area in the project. Learning about, for example, takt planning is very valuable.
- Logistics planning should be a multi-disciplinary resource that follows the project from the start to completion.
- The use of temporary storage for repacking, storage, smaller prefabrications, etc. is undervalued and has great potential. It would probably be beneficial if contractors joined forces to develop this use further.

Lean process planning

To give the entire team an overall picture of the total project and to better understand how everything is connected, the detailed design started with a thorough main process planning. In the KHiB project, two whole weeks were designated to planning, and the team met in separate conference premises. (Admittedly; nobody in the project knew what they were really in for.)

Statsbygg's project model with associated main milestones was the basis for placing the construction project's main processes in a system.

Process planning steps:

1. Define the main processes in the project. Normally, a construction project has 8–12 main processes. The definition of what they are, triggered lengthy discussions within the team. The limitation for the KHiB project: The team defined only main processes for the detailed design and construction phases. Previous and subsequent phases were not defined in more detail.
2. Within each main process, the team then defined the most important milestones in chronological order. These milestones were called key points. (Two separate terms were used in order not to mix up the project's main milestones with the main process' milestones.) Each process should generally not have more than 15–20 key points.

NB: The key points in the PCP plan are exclusively final points, i.e. when something is completed, finished, approved, concluded, delivered or closed. It should not be stipulated when an activity begins.

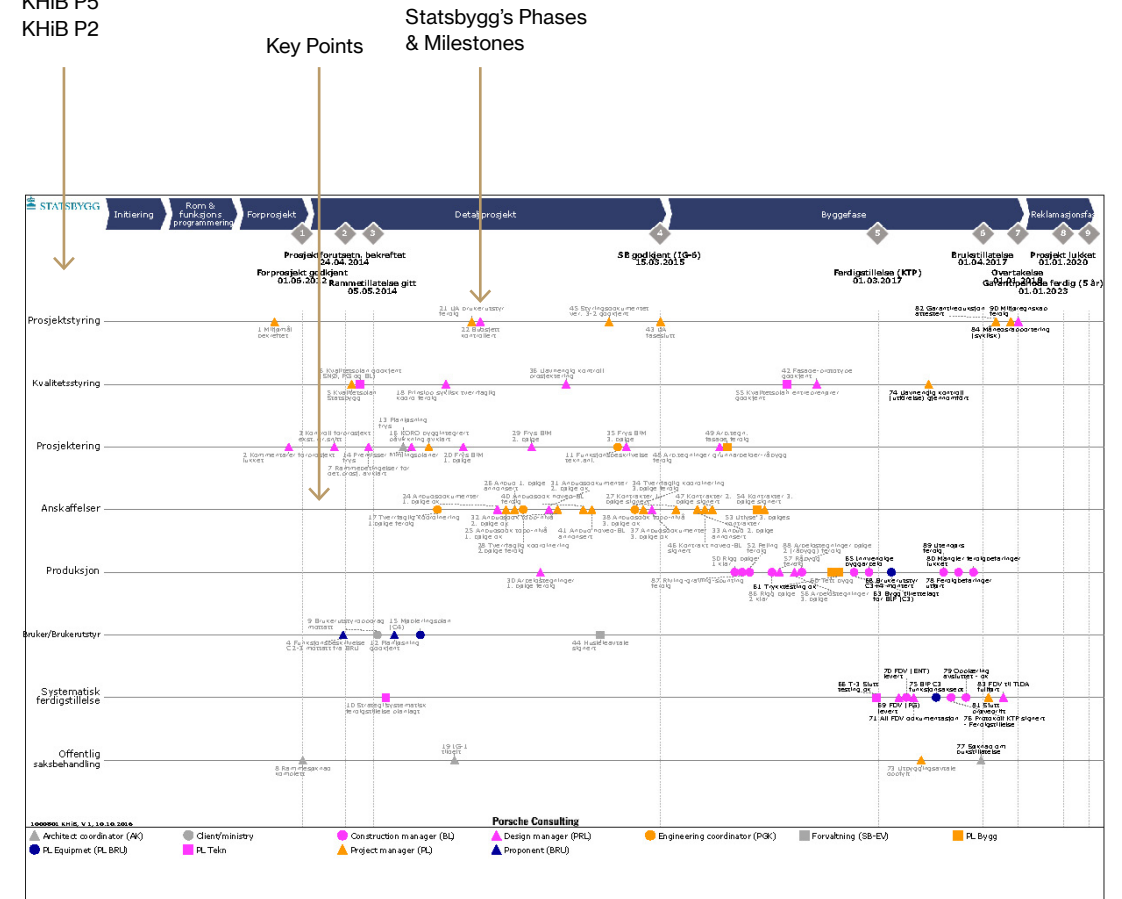
3. All key points were entered into the system in relation to each other in the PCP plan in which PCP = Product Creation Process. The PCP plan therefore became a clear map for important points that the project handles chronologically. It is important to be clear that the PCP map doesn't set dates/times.
4. All key points are finally described (detailed) point by point with input/activity/output and a completion deadline.
 - Input = Prerequisites in order for an activity to begin.
 - Activity = Describes briefly and specifically what is to be carried out.
 - Output = Conditions for the activity to be completed/ approved/concluded.Moreover, each individual key point should be assigned a responsible owner/approver who can be marked with separate symbols in the PCP plan. The description of key points is one of the most important activities in process planning. From each individual key point, reverse planning can subsequently be implemented.
5. The PCP plan should be assessed and updated regularly throughout the project.

PCP plan:

- The PCP plan is the project manager's overview for the project as a whole. The plan gives the team a joint overall understanding of all tasks and processes that lie ahead. Moreover, the team gets accustomed to thinking, managing, and planning with the help of processes.
 - PCP plans for multiple projects can be aggregated to create a reliable reporting tool that notifies a project owner (a portfolio administrator) of the status of the individual projects in the portfolio and what stage they are at. This assumes that main processes and key points follow a structured and incorporated system.
 - The PCP plan can also be used as a so-called maximum plan. For each new project, learning is accumulated (in the form of new key points). At the start-up of new projects, the plan is scrutinised, processes are selected or discarded, and key points for the specific project are established. This will thereby provide an immediate overview of what the new project should involve at a process and key point level.
- opprettes. Man får dermed med en gang en oversikt over hva det nye prosjektet skal gjennom på prosess- og nøkkelpunktnivå.

8 Main Processes

KHiB P1
KHiB P3
KHiB P4
KHiB P6
KHiB P5
KHiB P2



Pr. October 2015

KHiB P7 → Main process Systematic Completion

KHiB P8 → Main process Public Permission

Focus:

- Chronological in time
- Final points only



**Illustration: Statsbygg/
Porsche Consulting**
Main processes and key points in the PCP plan.

14-10 and 6-4-1 processes:

The main principle of the KHiB project is to be proactive, rather than being the usual reactive. An essential methodology to underscore this has been the two processes 14-10 and 6-4-1. This entails scheduling checkpoints 14, 10, 6, 4, and 1 week before the work in a given control area starts.

Put simply, the principle concerning 7 prerequisites for a sound activity is fundamental during all these weeks prior to start-up. (The 7 prerequisites are described in the chapter Lean Construction.)

The primary emphasis 14 and 10 weeks prior to start-up is rooted in the interaction between the engineering design personnel, site managers, and contractors. Complicated executions and complex dependencies are discussed. General multi-disciplinary challenges should be assessed, and solutions planned. Decisions should be taken regarding products with long ordering and lead times so that they can arrive at the construction site at the right time (the Long Lead Items = LLI). The level of detail is general. The engineering design personnel must participate in the meetings, but the contractors should also participate with their subcontractors and specified suppliers. In the KHiB project, the client took charge of the meetings.

In the 14-10 process there is particular focus on ensuring:

- that multi-disciplinary issues are identified and resolved
- that the project has produced all materials to be used in the construction
- that solutions to be used are constructible
- that products to be used are chosen (and suppliers contracted), and that deliveries are identified and secured at the right time.

The primary emphasis six and four weeks prior to start-up is the interaction between site managers and the contractors.

The 6-4 meetings assume that the general issues in the 14-10 meetings have been clarified and closed. Multi-disciplinary and mono-disciplinary dependencies must be discussed and coordinated, and technical and practical clarifications planned and resolved. The level of detail is specified. The contractors must participate in the meetings with their subcontractors and specified suppliers, but engineering design personnel should also participate. In the KHiB project, the client took charge of the meetings.

In the 6-4 process there is particular focus on ensuring:

- that all involved parties are prepared for the scope of the work in the upcoming control area and that no issues remain
- that all material has been received and reviewed
- that orders, logistics and deliveries are on schedule, and
- that all involved contractors and site managers are coordinated across all disciplines.

One week prior to start-up there is focus on verifying the 7 prerequisites for a sound activity. Issues from the 6-4 meetings should be clarified. Meetings should be conducted by the work team together with foremen the week before start-up in a control area.

In order to distinguish between the construction (geometry) and systematic completion (function) processes, the process for systematic completion is called 6-4-2.

6, 4, and 2 weeks prior to the respective test, a multi-disciplinary review will be conducted in which all different aspects of the test will be clarified and unified. The goal is to proactively ensure an approved implementation of the test as well as meet the acceptance criteria.

If the processes can be placed in a structured system, many unnecessary issues will be eliminated and a great deal can be gained. However, the cultural mentality change takes a while to introduce. The KHiB project was no exception.



Takt Time Planning for the main parts of the building:

The construction process (and the connected activities) for the large main parts of the KHiB building were specified individually: Concrete groundwork, shell, façade, roof coverings, technical rooms, stairways, interior finishing works, project hall, lifts, and outdoor areas. These main parts will have to be specified for each individual project, although approximately 80% of the processes that KHiB has described will also apply to other buildings. This is a unique and repeatable aspect of process methodology that the construction industry can greatly benefit from.

What must be conducted in any case for each individual project, are the specific main parts, the work volume calculations, and the subsequent progress planning. If the process methodology is set in practice and systemised, the construction industry can quickly become much smarter and eliminate a great deal of waste. The KHiB project used takt time planning on a weekly basis.

Experience/Learning process planning and PCP plan:

- The PCP plan is the first step towards standardising process planning for a construction project. The plan simplifies systematic ongoing improvements of both activities and processes in a simple and rational way.
- The process methodology can effectively be used to continuously improve and standardise progress planning, although a culture for working this way must be developed.
- Used properly, the PCP plan is a simple and very effective management tool.
- Process planning can effectively be used to prepare decision plans (for the client) and delivery plans (for contractors), and when deadlines for potential changes have been passed. The KHiB project sees the huge potential that exists here, but did not utilise these opportunities sufficiently itself.

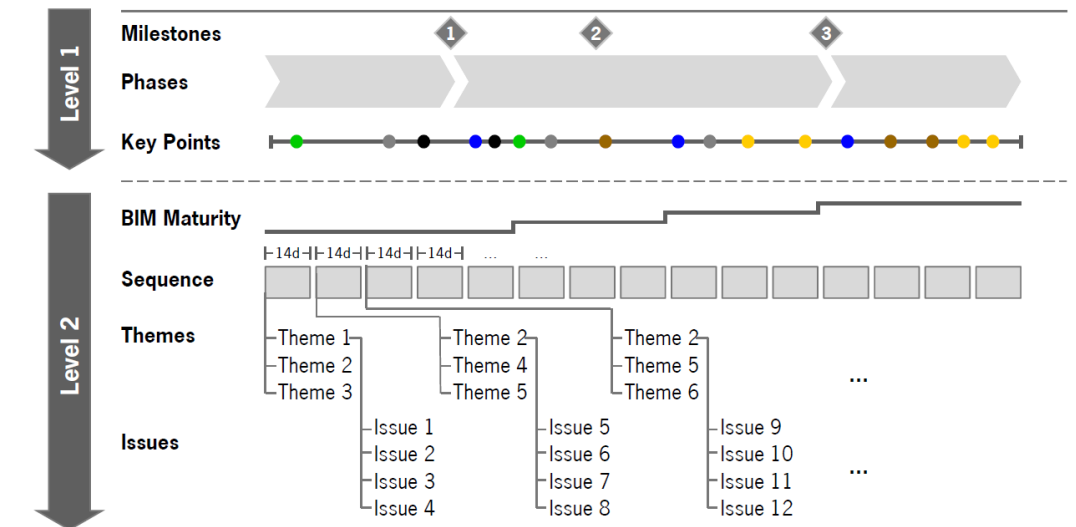
The relationship between phases and milestones via the PCP plan, process planning, and key points to the individual process' themes, takt time, and theme owners is illustrated in the illustration on the next page.

In the construction industry, process planning remains a relatively unknown phenomenon. Nonetheless, there are major opportunities for larger construction projects in particular to develop further structured and standardised process planning.

In order to connect the current system of level 2 to the overall level 1 process map the established working procedure was analyzed and illustrated

Level 2 Procedure

Schematic



BiM-Lean synergy effects
 The Design Main Process
 Increasing BIM-«maturity»
 2 Week takt
 3 Day co-location
 4 Step management of topics/issues

Illustration: Porsche Consulting
 Connection between process planning
 and a main process (in this instance:
 the design process).

The background of the image is a close-up of a wooden surface composed of horizontal planks. The wood grain is prominent, showing concentric growth rings. There are some natural imperfections, such as a small vertical crack in the second plank from the left and a small hole in the bottom-left plank. The text "Lean Design" is overlaid in the upper right quadrant in a bold, black, sans-serif font.

Lean Design

Design and the design group in KHiB

What is design

Broadly speaking, a construction process can be divided into Programming – Design – Construction. These processes normally proceed in phases, and there are different phase models. In recent years, the construction industry has tried to reach agreement on a joint model based on the RIBA standard (RIBA = Royal Institute of British Architects). The KHiB project has followed this model. Design intends to unify the complex picture of all stakeholders' interests, which then have to be materialised in the completed building.

What is design management

Design management is the overall management of the design for the construction project. It is important to distinguish between coordination and management. In general terms, coordination is about delegating tasks. Management is about performance: motivating the stakeholders involved to perform tasks achieving the project's defined objectives. Objectives include:

- Society objectives
- Functional objectives
- Aesthetical objectives
- Progress objectives
- Financial objectives

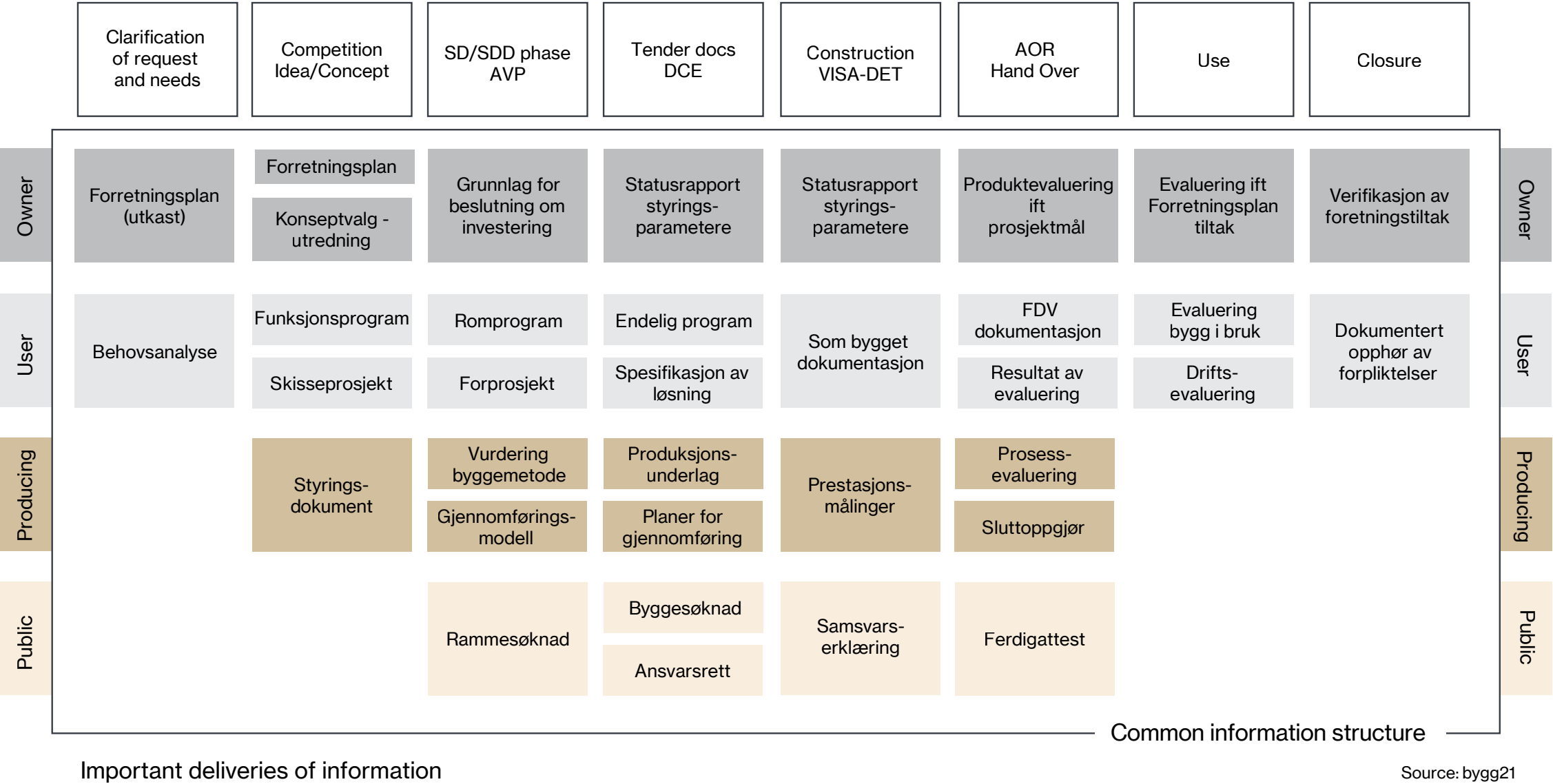
Design management requires interdisciplinary competence in both design and production. And, finally, it requires management competence, particularly regarding what may be called relationship management: being the link between different stakeholders, not just during design.

What is a design group

A design group is an interdisciplinary team of specialists who provide expert input and output within the fields that have to be examined for the building to be constructed in accordance with defined objectives and programme requirements. During a complex building project, there can be 15-20 different specialists participating within the project over the period during which the design group is involved. However, some consultants will virtually always make up the core group: The architect, the construction engineer, the HVAC engineer, and the electrical engineer.

Photo: Snøhetta





Viewing design as a production form

With Lean methodology as a backdrop, the KHiB project has chosen to view design as a form of a production line. When viewing design in terms of a production line, one must think in processes.

What is a process

The KHiB project has defined a process as a set of activities that interact, in a logical order, to arrive at a common product.

What is the common product of design

The KHiB project defined the overall common product as being the BIM model itself. This model then becomes the realisation of the building. The transition from the BIM model to the physical building is continuous. Construction starts before the design group has completed its work.

The 5Rs

To maintain the order of the interdisciplinary design, the stakeholders worked jointly to plan the most important key points (which for KHiB relates to milestones in the processes) and the end products for the detailed design and the construction phase. These must be executed in the right order and the logical order.

As a consequence, this leads to a central principle of Lean: the 5Rs. As the design progresses, the designers must with an interdisciplinary approach ask for:

- the **Right information**
- at the **Right level of detail**
- at the **Right time**
- in the **Right amount**
- for the **Right area**

The following pages describe the challenges encountered and how the KHiB project chose to solve them.

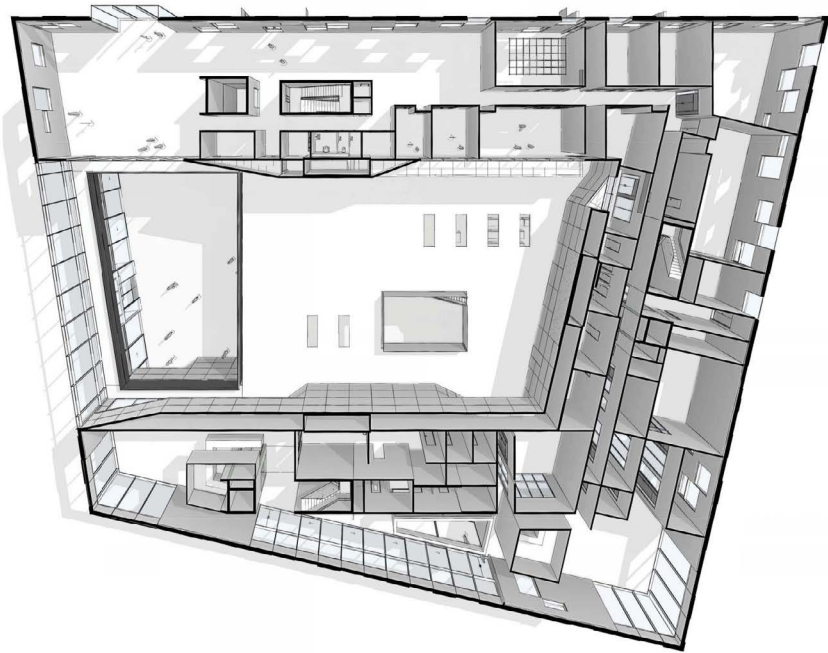
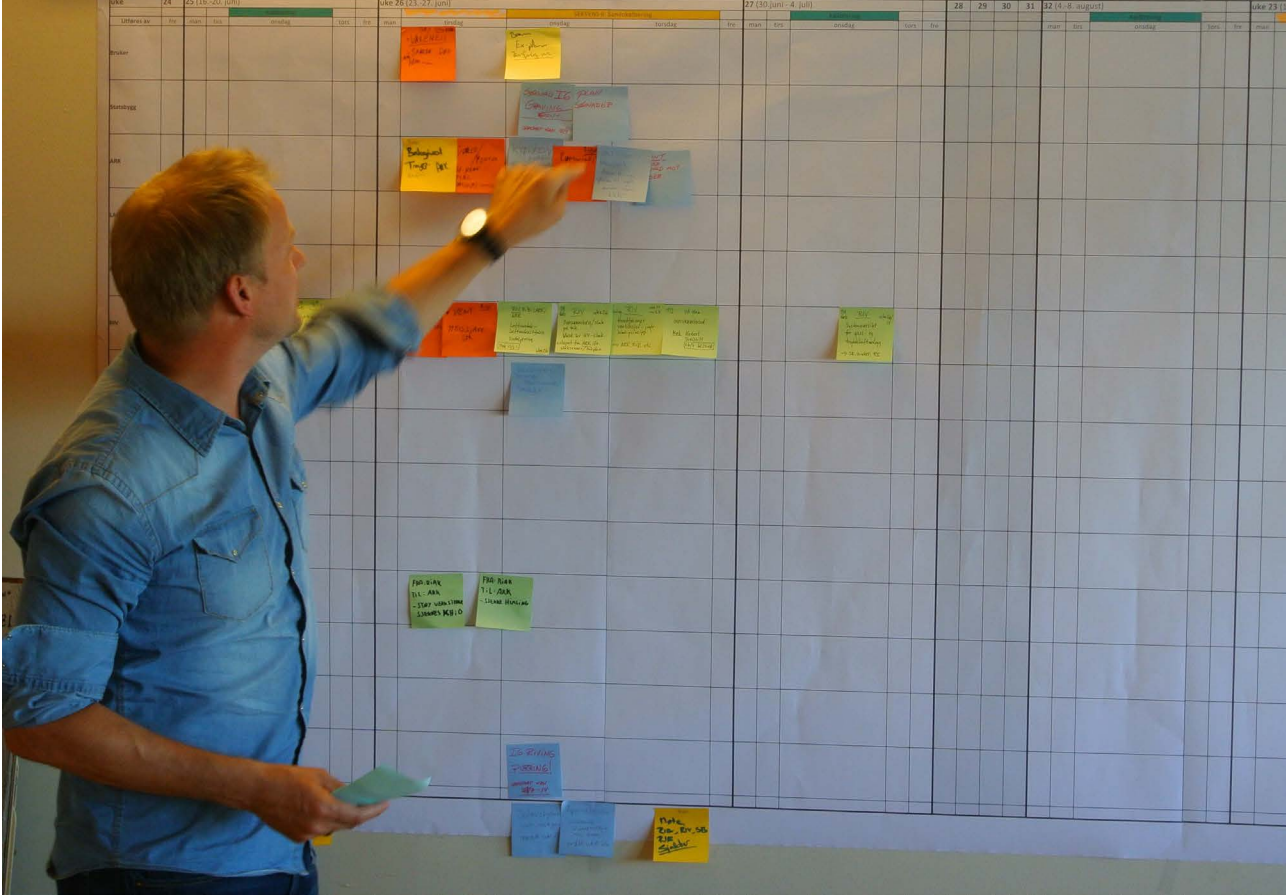


Photo: Statsbygg
Hans Thomas Holm

Illustration: Snøhetta
Axonometric projection of the model

The challenge

The design process is complex and iterative. The large number of parties involved, growing complexity and a high degree of specialisation combined with new tools generate continuously increasing information volumes that need to be managed. Design can be compared with an elephant, which is large and unmanageable. Questions asked internally were the following: How can we achieve control of the information volume and divide it into manageable and controllable pieces? How can we create a form of production that benefits all the parties and benefits the project?

The challenge is to optimise the specialist's input during the design process. We often mess up when, and at what level of detail, the deliverable should be received. A design group spends a lot of time on non-value added work, including waiting time in meetings and lack of interdisciplinary communication. This often leads to large iterations or work linked to administration of the different stakeholders' internal management systems.

Below find described in more detail how the KHiB project chose to solve the challenge of handling large information volumes.

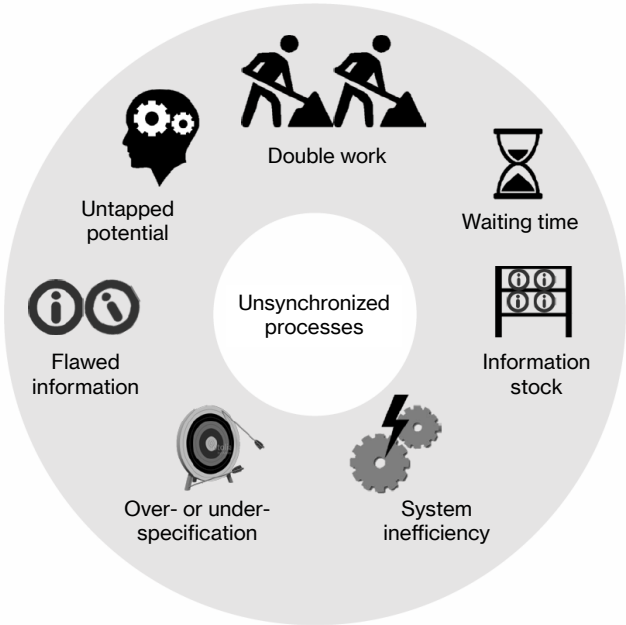
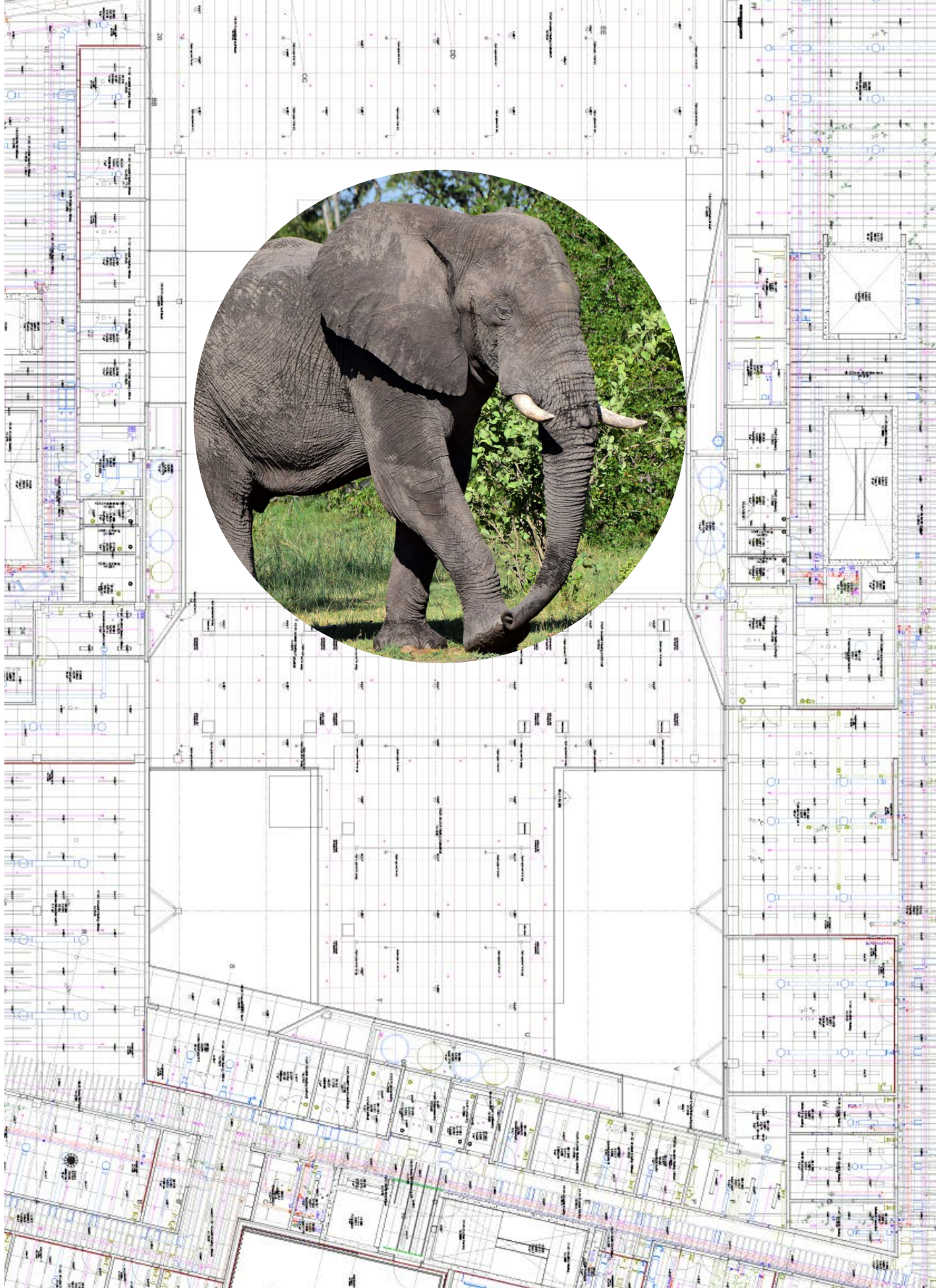


Illustration this page:
Porsche Consulting
Different types of waste

Illustration next page: Snøhetta
Unmanageable design volumes –
the «elephant» and the ceiling plan



The identification of processes

The KHiB project began by identifying its main processes:

- Project Management and Control
- Quality Management
- Design
- Procurement
- Production (or Construction)
- User Equipment / User involvement
- Systematic Completion
- Public Permissions

The processes are listed in a main processes map. This map is the project's main strategic tool.

For each process, we have defined and placed process milestones, called key points, in logical order. Each key point describes an endpoint with its deliverables. Each key point has been appointed a dedicated responsible owner.

The KHiB team spent a total of two weeks drawing up the process map at the beginning of the detailed design phase. These weeks gave all the project participants a very good interdisciplinary understanding of the order within each process and the cross-functional connections between all processes of the design phase that was getting under way.

For the design phase, which is the subject of this chapter, the project endeavoured to prioritise flow efficiency over resource efficiency. By flow efficiency, we mean a continuous inflow of relevant information into what is defined as our shared product, the BIM model. The resources must be available when the product needs them, and not vice versa. Our mantra was that all stakeholders have to be present for the common goal: the right information at the right time into our mutual BIM model. The virtual model is defined as the basis for the physical building that will gradually be built, completed and then be taken over by operations and the user.

The process map

Statsbygg's project model with associated main milestones is the basis for systematising the construction project's main processes in a process map.

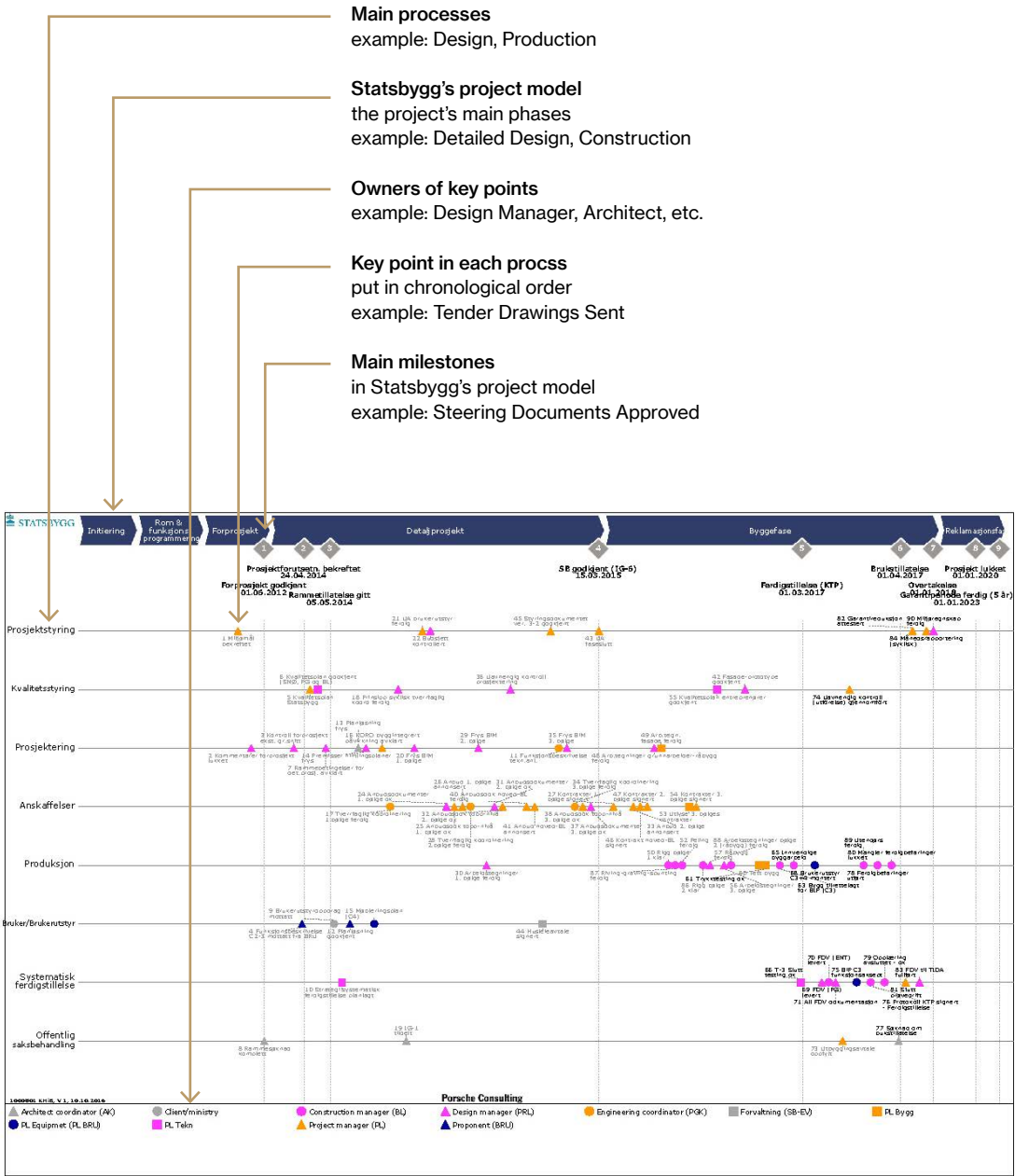


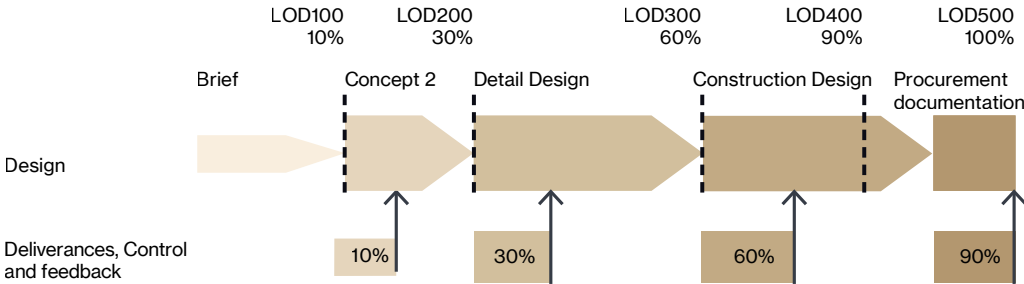
Illustration: Statsbygg
The project's main processes map

Dividing the information volume

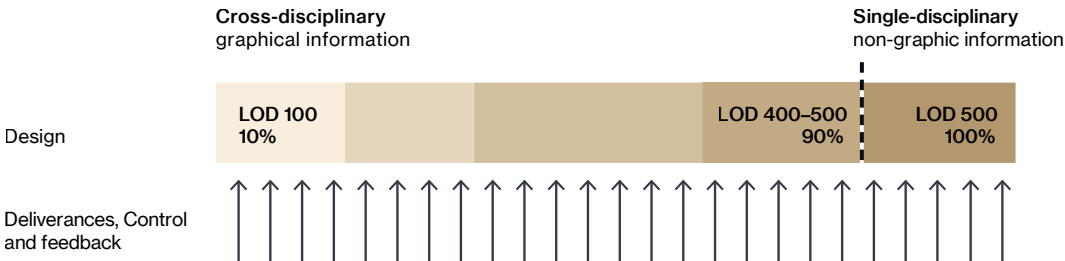
Most of the project models are divided into phases, e.g. Preliminary Project Phase and Detailed Design Phase. These phases are usually managed on the basis of classic delivery plans, where large information volumes are supplied at the end of the phase and then evaluated. In complex building projects, this makes the total information volume to be evaluated disproportionately large. In addition, the feedback is often received some way into the next phase, when the project's level of detail has increased. Incorporating it can be very time-consuming and complex. It is virtually impossible to keep control of all cross-functional connections. This impacts on both cost and quality negatively.

The KHiB project divided the information volume and the decisions into a large number of small, manageable pieces. We then chose a delivery rhythm, which we called the takt time of the design phase. This enabled the participants to keep a continuous check on deliverables throughout the whole design period. A resulting major benefit is greater predictability of the process. The size and the content of the deliverables are adapted to the chosen takt time. This results in an even production and a continuous exchange of information between the stakeholders involved. The KHiB project had the client (decision-maker) present throughout the complete process, making it possible to carry out continuous checks.

Traditional procedures



The KHiB procedure



The KHiB procedure



Illustrations: Snøhetta
Above: Takt time division during the design phase in the KHiB project
Below: Continuous deliverable checks in the KHiB project

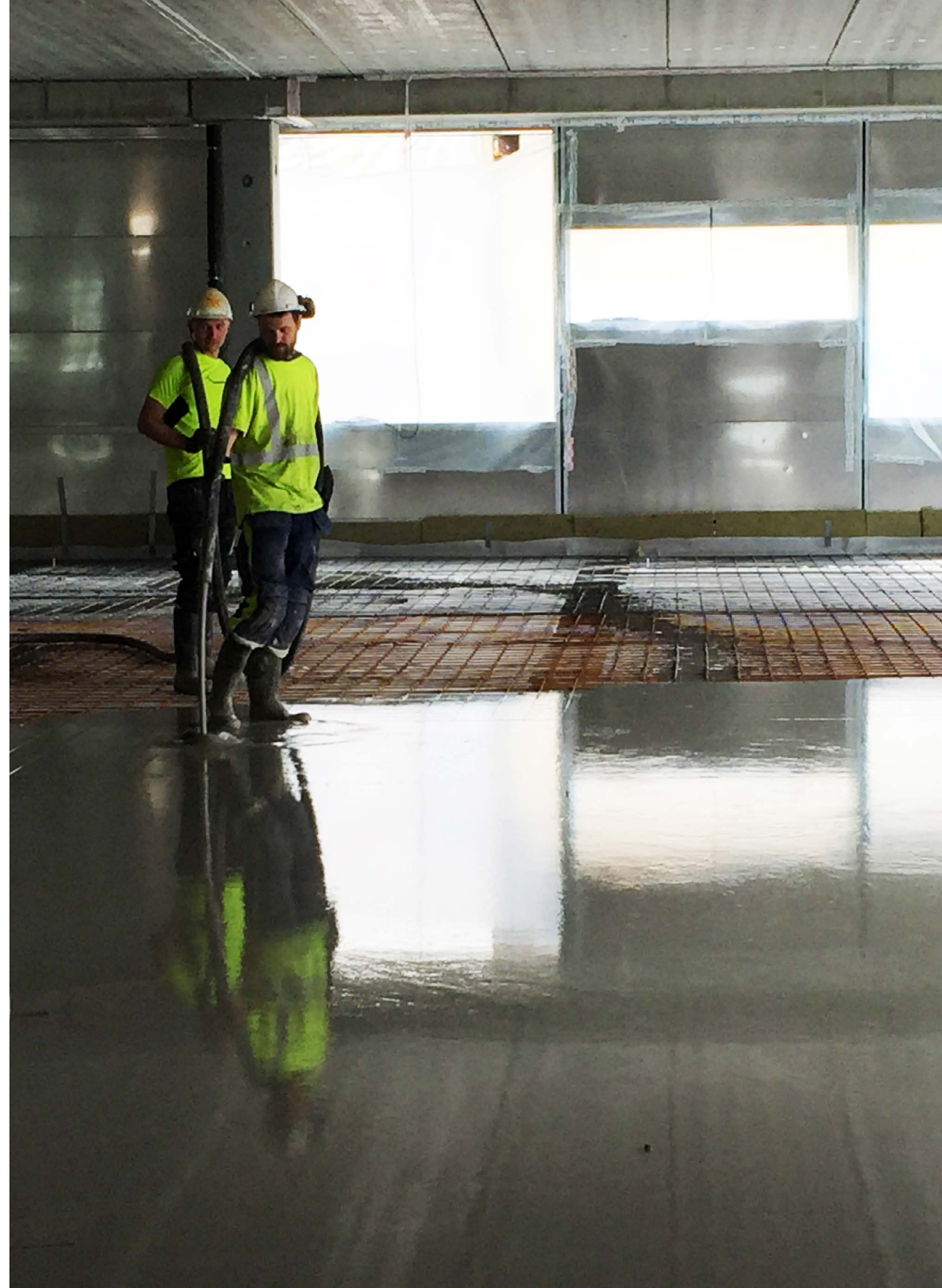
Takt planning of design

Takt time planning in design means planning and dividing the project's processes and activities into an even rhythm that also is adapted to regular meeting sequences. In the KHiB project, we chose to co-locate three days once a fortnight and meet on one day in the week in between. This gave the project completely regular sequences. For every sequence, we delivered packages with a clearly defined interdisciplinary content that had been requested and agreed upon in advance. An important principle of takt time planning is to only request delivery complete. Every 14-day sequence began with asking about the status of the packages. Everybody was involved in this, ensuring that all the participants gained an overview of missing deliverables, for example. If the shortcomings were considered serious, the decision could be taken at the project's strategic level to pause the design until the deliverable had actually been delivered.

The overall content for the sequences was decided at the project's strategic level and incorporated in a plan for the entire process. The detailed content for each package (the deliverable) was requested, evaluated and defined at the operational level every 14 days. Operational level means the professional expertise around the table. Planning the long-term and the short-term content of the overall plan and packages requires experience and understanding of both design and production. This planning is crucial to how well (i.e. Lean) the actual design process flows. As previously mentioned, the process plan was the project's overall roadmap for the connections that had to be taken into account at any given time.

This goes back to the point about prioritising flow efficiency over resource efficiency in the design phase. The project invested in front-loading (i.e. early and correct planning) to obtain an overview of problems that could become, and represent, risk elements in the project. As a consequence, a correct design basis will also lead to less errors on the construction site, which benefits the building in terms of progress and quality.

Photo: Snøhetta
Astrid Renata Van Veen



Package content principles

We previously mentioned the fact that we have a cross-functional design that has to be carried out in the right logical order with a focus to produce the BIM model and other relevant information. This documentation then provides a future building. We further mentioned that the 5Rs are important to Lean, and we introduced the process map as the project's guiding strategic overview tool. The map enables us to see the connections between the various processes in the project.

The information volume in the design can be viewed as «an unmanageable elephant». The design is one of the main processes in the project. To make it manageable, it is divided into a large number of smaller pieces, or packages, and these packages have to be delivered every 14 days.

What are the principles followed with regard to the content of the packages? How do we know what has to be delivered at any given time? An important factor is the definition of added value. It defines what information provides optimum input (value) at the right time.

At the outset, the BIM model is quite empty for any kind of information. We must define what information has to be added, which then can be defined as the actual skeleton of the building. This information is the BIM model's general level. The model is then developed from a general (generic) to a specific (detailed) level. This is nothing new, but design teams frequently tend to approach it unconsciously. And it is generally not communicated clearly enough between all the interdisciplinary participants.

- **Principle 1:** Relevant content at the right level at the right time. Information that one discipline regards as delivered may be inadequate or insufficient for other disciplines. This leads to the next principle:
- **Principle 2:** Mono disciplinary production (from one discipline) cannot start before all the multidisciplinary information has been entered in the model and agreed between all the participants.
- **Principle 3:** An even flow of interdisciplinary information, with the right complexity, adapted to the design takt time. The third principle regards the size of the interdisciplinary packages.

Illustration: Snøhetta
Flow in the BIM model
and deliverable packages

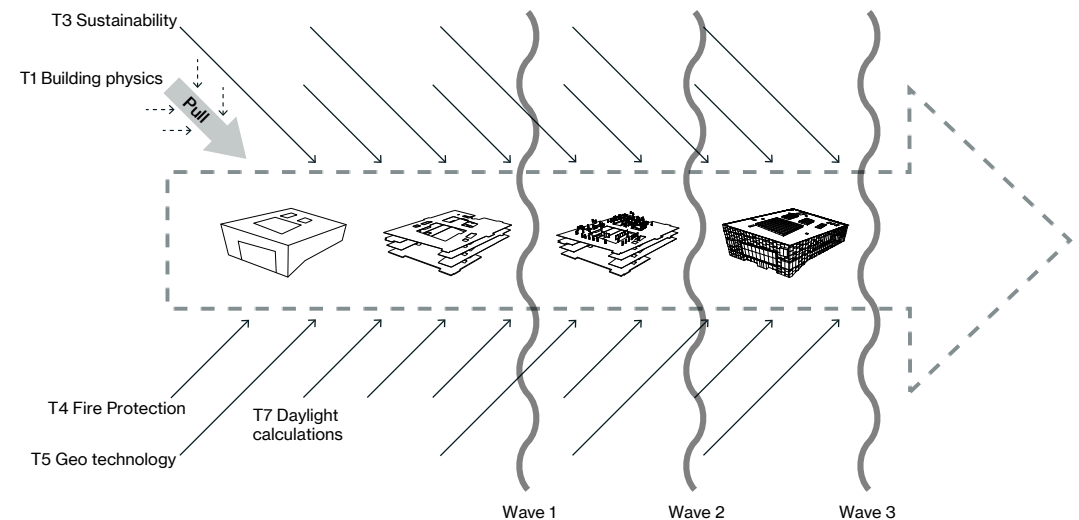
From general to specific

All elements in the BIM model must be logically developed from a general to a specific level (Level of Development, LOD). It is a strategic prioritisation of when which topics should reach a given level at a given time in the course of the design. This assessment is dependent on a number of factors, such as the logical order of input, tendering strategy, construction sequence, guidelines from third parties, etc.

In the KHiB project, the order was prioritised jointly by the design group. Ideally, this assessment should be anchored in the project's BIM strategy.

In our case, the deliverables from the design group were controlled in accordance with the need for documentation for three different tender packages, in the project known as tendering waves. The tender package for façades, for example, went out very early, which provided direct guides to the level to which the building's load-bearing structures and floor slab front edges had to be prepared. Each project will have its own set of rules for this. The documentation from RIB (Rådgivende Ingeniør Bygg = Consulting Engineer Construction) will be decided long before the documentation for ceilings, for example.

The package content principles must be communicated clearly and in the most rational way possible to everyone involved:



The impact of big room

Complex projects face many challenges. Ensuring exchange of information that is as smooth as possible between the various participants is a key issue. The section «Viewing design as a production form» mentioned how the information volume was divided into small, manageable packages. This approach helps us keep the deliverables and information volume under control.

Information exchange and flow

The next challenge is how to create the best possible flow in information exchange. Information exchange means the interdisciplinary and mutual exchange of expertise and relevant data based on a common understanding of what point in the process the project has reached. The aim is for the consultants to provide continuous, optimum input at the right time. The decision to co-locate is an important measure in facilitating information exchange.

The KHiB project established a shared office, called big room, where all the key participants in the project had to be present on co-location days. This applied even if just a few meetings were scheduled for the participant in question. The participants had full access to the necessary facilities on a par with their usual place of work, and they could work on other projects if their time was not fully taken up with KHiB issues. This enabled us to achieve optimum accessibility for any questions that emerged.

Transparency and culture

One of the greatest benefits of working together closely is that you come to understand each other's disciplines and challenges to a greater extent. You establish a joint culture and attitude to the project, you get to know each other as people, and this makes it important for everyone to deliver as promised. Maintaining a constant focus on team culture proved to be one of the most important investments on the part of management. Solidarity was further strengthened by agreed and recurring routines during the co-location days, as well as by joint use of tools.

Photo next page:
Statsbygg, Trond Isaksen

Above: Meeting schedule during
co-location
Below: Transparency and culture



Structure and admini- stration of theme logs

As described in the section «From general to specific», all input for the BIM model in the KHiB project was organised in interdisciplinary topics. Each topic had and maintained a theme log, which had a topic owner. The topic owners in KHiB were selected discipline managers.

The theme logs are used to list the activities and issues that have to be carried out for the topic owner to be able to complete the topic. The content of the activities in the theme log, the size of an activity, and the number of parallel activities are adapted to the BIM model's maturity and the takt time. As a general rule, no activity should be larger than to be carried out in one sequence, i.e. in the course of 14 days. The topic owner is personally responsible for adjusting the scope of parallel activities within what is possible in the course of the takt time period. The principle of prioritising flow efficiency over resource efficiency applies here too. If necessary, the topic owner's team is enlarged in order to maintain the overall design takt time.

This process is based on the Lean principles of «takt and pull». The topic owner «pulls» in the necessary activities (information) to maintain the design takt time. The activities are reviewed jointly at the start-up meeting at each fortnightly co-location. The KHiB project marked the status of the activities in green (done), yellow (unfinished) and red (not started) in a joint log. This enables everyone to see which tasks are on schedule and which have not been completed. Each theme log also has a second page, where important decisions are logged. Due to the logs, the KHiB team did not need to keep minutes. Although the theme log was perceived by some as extra work (particularly by those who are usually spared having to write minutes, perhaps), it proved to be a very dynamic tool that saves the project work in the form of waiting and tasks not being carried out. Together with the visual planning at the beginning and the end of each of the co-location days, the theme log provides all participants with an extremely good overview of completed, expected and outstanding tasks. It ensures control and transparency, as well as providing good documentation of the BIM model's development and maturity.

Delegated ownership of deliverables is another important benefit. Each individual specialist consultant has a clear responsibility for coordinating their interdisciplinary topic. Each individual is also fully responsible for the agreed deliverable.

Illustration: Snøhetta
Theme log

Serial number theme log
example: T39

Theme example: Technical room		Activity example: «Move electric cabinet»		Input (comes from) example: Electric engineering consultant		Input (is given) to example: Architect			
Theme owner example: Architect Frank		Specified area example: Plan 5 Technical room							
T39		T39		T39		T39			
Tittel: Typiske rom		Tittel: Typiske rom		Tittel: Typiske rom		Tittel: Typiske rom			
Aktivitetsleder: Frank D Kristiansen		Aktivitetsleder: Frank D Kristiansen		Aktivitetsleder: Frank D Kristiansen		Aktivitetsleder: Frank D Kristiansen			
Etablert dato: 31.10.2014		Etablert dato: 31.10.2014		Etablert dato: 31.10.2014		Etablert dato: 31.10.2014			
Typologi	Visuell plan	Aktiviteter/ hva (output, beslutning)	Innput fra	Innput til	Status	Krever endringslogg	Beslutning nummer	32 (SEKVEN 7)	
								32	33
								04.aug	11.aug
K205		revidere angivelser reaktor oppgraderingsplan	RIB	ARK	OK				
		Boring av brønner kan tiltaksplaneres K205.	info						
		trekkerer til grensesnittet K207 RIE på tegning	RIE	RIB/ARK	ok				
		Vei opp langs eks bygge felt vekk fra nabofasade		RIV/RIB					
		påstap over bunndekke overføres til K206. Unntak: Gulv trapper og teknisk rom. - RIB: hvoretatt	RIB	ARK	ok				
Plan 5									
teknisk rom akse 3 til 6		Et skap flyttes til langsida trapp og ved akse 4. RIE: OK, tegnes inn	RIE	RIV/ARK					
		Uttak luft høyere enn inntegnet på ARK revit. Like høyde som glassoverlys. Skisse fra Frode Holthe følges.	RIV	ARK/RIB					
		Sluk i tekniske rom med lokalt fall for aggregater. RIV ser om leverandør kan levere ferdig løsning. Tegnes inn i denne omgang. RIV tegner inn på sin fil	RIV	ARK					
		Inntak luft i fasade må koordineres. Tas når leverandør fasade er på plass. Skisser diskutert under sekvens 14.	RIV	ARK					
		Isolert vegg rundt tørrkjøler flyttes til ytterkant betongvegg rundt trapp 2. justere gulvoppbygging og tak.	ARK	RIB/RIE/RIV					
		styring av røykluker i trapp. Elkabler utenom trapperom.							
Plan 4 Del 1		Generelt gjennomgå posisjon av trykkluft for rom.	Bruker	RIV					
fotostudio		Trykkluft ved vask. Info	RIV	ARK					
		Etablere en oversikt over vasker/kum med eget avløp til oljeutskiller og kjemikaliehåndtering. Hvordan skal disse se ut?	Bruker	RIV/ARK					
		Bro må tegnes som familie og legges som utstyr i rom: C2. Gjøres etter gjennomgang per etasje	ARK	PG					
		Innhente info fra bruker vedr lysrigg	Bruker	ARK/RIE		006			
		Detektorer i forhold til kald røyk. Gjelder også videostudio. RIE: Vurdere utkoblingsenhet. Diskuteres med RIB	RIE	PG					
mørkerom		Få vekk synlige dioder fra himling. RIE: RIV må også være oppmerksom på dette ved plassering av motorventiler, speil etc	RIE	PG					
		Hygiene himling tykkelse 20mm(?). ARK/Riaku undersøker. Riaku: Tykkelse på plottene 20mm. Nedhengt fra dekke. Total konstruksjonshøyde (minimum): 150mm.	ARK/Riaku	RIE/RIV					
		Strøm til mørkeromsluser	RIE	PG					
		lysbord i korridor trenger strøm. Stikk i korridor	RIE						
		Blandeskap(C2) skal ha avtrekk. Se på plassering.	ARK	RIV					
		Se på høyde himling. Justert ned til H:2700mm	ARK	PG					
		06.1.023: kan LED lys integreres i avtrekkskette? RIE: Kan avtrekkskette leveres med integrert lys?	RIE	ARK					
Printshop		Legge inn treulthimling	ARK	RIV/RIE					
		Stikk langs gulv	RIE	ARK					
Te kjøkken		Legge inn overskap i Revitmodell: C2	ARK	PG					
		Legge inn kjøleskap og oppvaskmaskin i Dofus: C2	ARK	PG					

Systematic completion in design

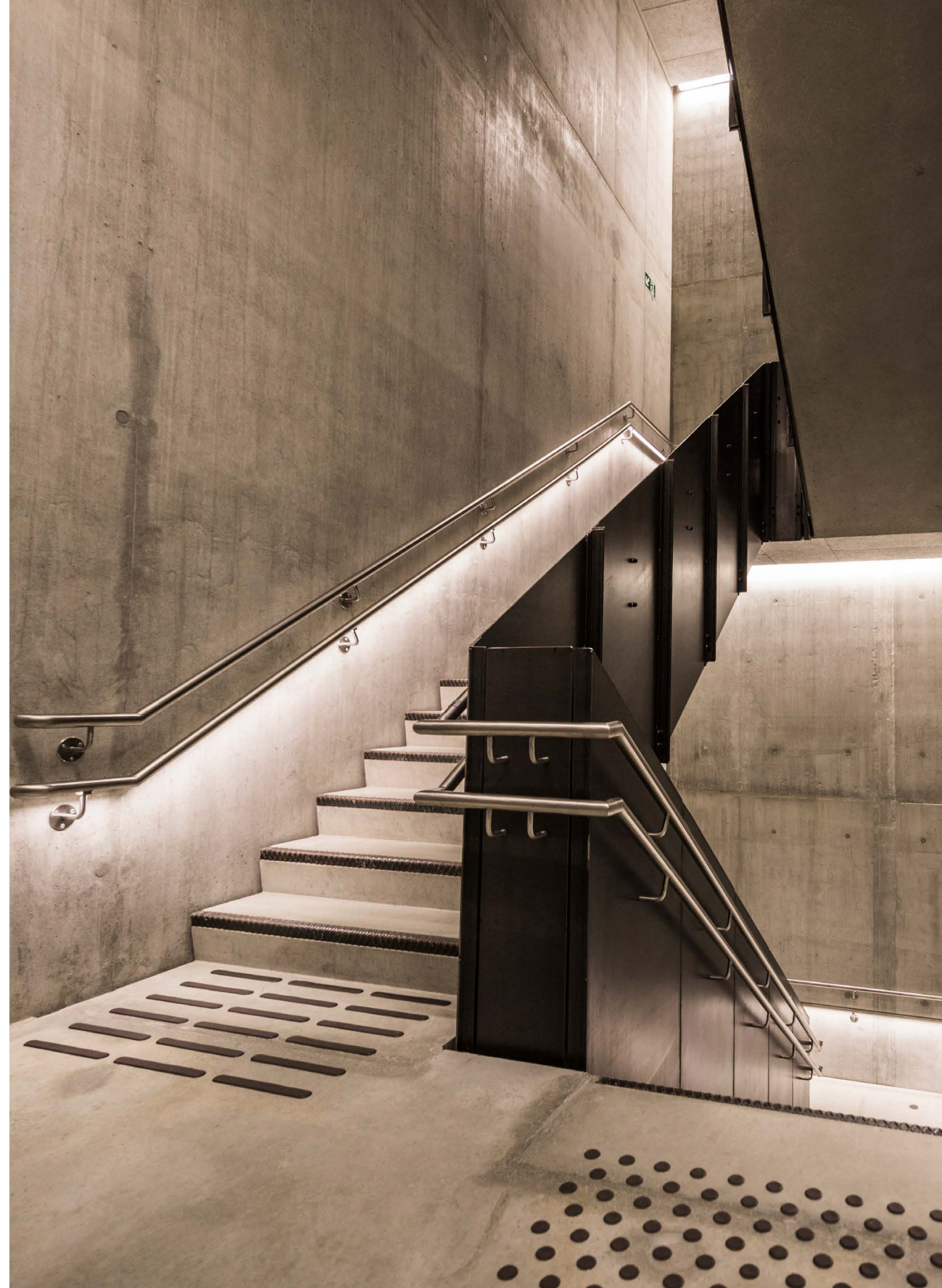
A building is made up of a number of spatial and functional requirements that have to interact in such a way as to meet the needs of the people using it in the best possible way. It is the task of the architect to shape this into a whole. The starting point is the user's and/or client's requirements and objectives. Those requirements establish the premises for the building's identity, as well as for its technical and spatial solutions. The interaction between all these parameters is implemented in interdisciplinary collaboration in the design group.

KHiB is an academy of art and design with a great number of complex technical requirements. Among other things, the building has several workshops with special installations with associated ventilation and power requirements. Systematic completion provides assurance that the project has defined and met all the technical requirements involved in accommodating the building's functional needs. The process focuses on how to plan, design, realise, test and operate the technical systems in a controlled manner with as few errors and problems as possible.

The Lean mindset and the systematic completion process go well together, with the process becoming a natural part of Lean design.

In KHiB, systematic completion began in the detailed design with preparation of the document «Systematic completion requirements». This document defines requirements for suppliers with regard to the construction, the tests and the inspections of the technical systems. The requirements were implemented and followed up throughout the detailed design, the construction phase and the trial operation period. The result was that the trial operation period commenced on schedule and the operating organisation was able to take over the building from day one.

Photo: Snøhetta
Stephen Citrone



Site collaboration

14-10 and 6-4

Every second Tuesday (and also on the according Wednesdays during the first half of the construction phase) all the parties involved, i.e. consultants, contractors, users, operating personnel, site managers and project managers, would meet to develop and finalise the design documentation into completed work documentation. This teamwork in the building phase, which was named «Super Tuesdays», was an extension of the design team collaboration meetings every fortnight.

The principles for the meeting were the same as in the detailed design. The person responsible for a topic provided the information and resources needed to clarify and deliver the topic on schedule.

Clarifications from the 14-10 and 6-4 meetings were a fixed item on the agenda for the Super Tuesdays. The 14-10 and 6-4 meetings, attended by the site management, designers, suppliers, and contractors, were held once a week. General challenges across disciplines and solutions were assessed, coordinated, and planned in principle 14, 10, and 6 weeks before start-up on the construction site.

The purpose of meeting 14-10 weeks before execution was to stay abreast of product clarifications with long lead times (e.g. door environment, distribution boards, and energy plant), for example, and ensure interdisciplinary teamwork between the various suppliers and the contractors and their subs. On the KHiB project, the meetings were chaired by the client.

The 6-4 meetings assume that the general items and the issues from the 14-10 meetings have been clarified and closed. The 6-4 meetings is the arena for the cross-functional teams that are to construct the building. At the meetings, the BIM model was reviewed, installation and installation order were discussed, and any non-conformances were dealt with. In addition, execution was discussed in separate meetings with the individual disciplines. The meetings could ultimately affect details that had already been worked out. On KHiB, the meetings were chaired by the client, represented by the site management.

14-10-6-4-1 can be regarded as an ectented 7 conditions for a sound activity. The illustration on the following page shows the degree of involvement by different stakeholders ahead of start-up of an activity in a control area.

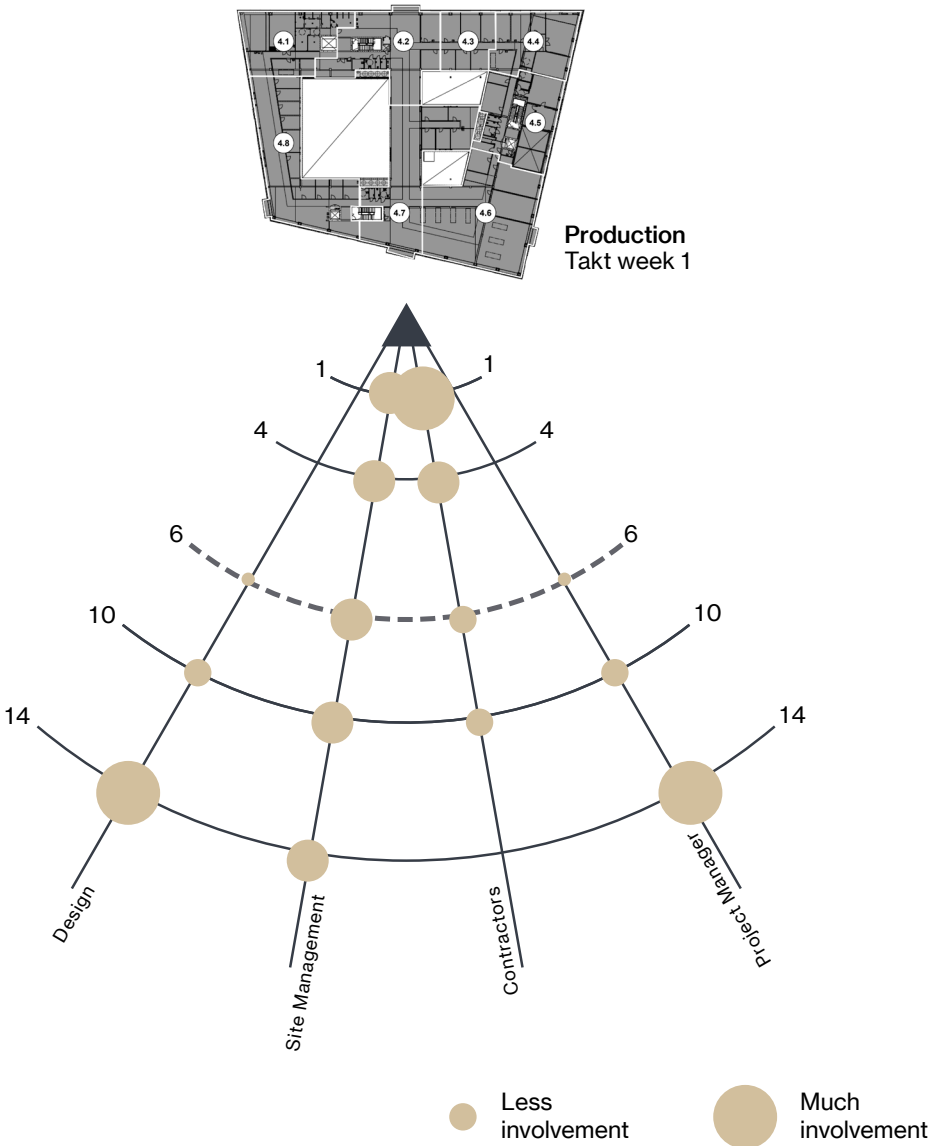


Illustration: Snøhetta
Degree of involvement by different stakeholders as start-up in a control area



BIM

BIM is a tool that makes three-dimensional design and information exchange possible. In other words, a room and its elements are modelled from all sides. In the 3D model, it is also possible to link all the desired information to the drawn objects and information on the construction project in one place.

The letters BIM stand for:

- B = Building
- I = Information
- M = Modelling (the process) / Model (the product)

The BIM model can also be connected to time/progress (4D), cost/finances (5D), and intelligent linking between an As-Built model and lifecycle management (6D). The 4th, 5th, and 6th dimensions are not used much yet. In the future, it is probable that the BIM model will provide complete documentation for design, construction, maintenance and completion of a building.

Our main focus in the design was to ensure good flow into the BIM model. The design team therefore has to establish an awareness of what elements need to be completed to what level and when. This is connected to the priorities and connections we illustrated in the process map, which shows when the endpoints of the different works on the construction site are.

The maturity of the BIM model can be defined by the term LOD, and by defining in purely progress-related terms when to freeze areas or topics in the model. Freeze therefore means being finished with entering predefined information in the model, at the right level. LOD can be compared to pixelation in a photo, or looking at an object from far away or close up: From a distance, one is only able to see the shape. When one is very close to the object, all the details are visible; you are at the highest level of detail. And there is also access to all relevant information on the object. In BIM language, this is LOD 500.

The model makes it possible to see how a building will function when it is completed, and one can check that the building is buildable. The competence and experience of the entire design team is a critical success factor in this respect. Being planned in BIM does not make a building good to be in, buildable or easy to maintain. A building is successful because the design team understands the challenges and finds good solutions.

A clash detection tool can be used for design in the BIM model. The purpose of clash detection is to identify possible conflicts and clashes between disciplines in the model. In the KHiB project, clash detection was a fixed part of the fortnightly teamwork throughout the detailed design up until the production documentation was complete. It is important in this context to remember that clashes cannot occur between elements that are missing in the model. You also have to be aware which elements have been frozen and which have not. Clash detection is just a supplementary tool. The BIM model's maturity reflects the information that has been agreed between the disciplines. Therefore, at any given time it will only to a limited extent show how complete the design documentation actually is.

Visual review of the BIM model as part of the teamwork is another way of using the model. «Walking» through the model provides information on the progress and how to furnish the rooms, and it forms a useful decision basis for the client and the users of the building.

In the KHiB project, the model was also the production basis, incl. documentation, on the construction site. We used the model to ensure buildability. The model was used instead of drawings in much of the building production, i.e. the project did not use paper drawings much. In the project, we modelled, among other things, reinforcement and ventilation ducts, which were then used directly to take off quantities and build from. The contractors, their subs, and the suppliers made extensive use of iPads to export relevant information, and BIM kiosks were located at regular intervals in the building.

Reflections and experiences

This chapter primarily deals with the KHiB project's experiences seen from a design team point of view between the start of detailed design and the building being commissioned. The guiding principle with a view to full handover of the building was first and foremost realisation of the building's overall objectives, including functional, aesthetic, environmental, progress-related, and financial requirements.

The strategic management of the project focused on these objectives and motivated the participants to achieve them by concentrating on project flow. This backdrop inspired everyone involved in design to discuss on an ongoing basis how best to perform the interdisciplinary tasks.

The design team gave the building a visual form and unity, simultaneously meeting all the technical, structural, functional, social, symbolic, and financial requirements. The KHiB project taught us the necessity and value of good interdisciplinary processes. It gave us a valuable insight into how incredibly complicated it is to get everyone involved to interact. The project developed and applied a Lean mindset. We used new tools to optimise flow between the different participants. Lean methodology was a shared guiding principle and inspired continuous assessment and improvement of interdisciplinary work processes and information exchange.

An understanding of the connections between the various processes running in parallel (the process map) and the ability to break down the information volume into small, achievable pieces were success factors in the project. The construction client's focus on Lean enabled the team to try out new methods for better teamwork and joint management by objectives.

The methodology and accompanying tools for Lean design represent ground-breaking work developed by the KHiB project. The project has shared its knowledge widely. We warmly recommend that future projects should take advantage of the combination of Lean design, BIM and Lean process planning. The synergy effects and the potential it offers are enormous.

Photos: Statsbygg

Above: Trond Isaksen
Big Room on site
Below: Hans Thomas Holm
Takt time training at the
Porsche Academy



Systematic Completion



Systematic completion in brief

A large construction project takes years to complete, in some cases, decades. It all starts with an idea. This idea is explored and verified according to regulatory provisions and utility value. If the idea is sustainable, the project moves forward to the engineering phase. This phase involves several decisions to be made throughout the draft project and preliminary project, and in some cases, each of these projects require several rounds. Once the project is finally decided, the construction phase is initiated, starting with detailed engineering. From here to the completed building, the project is run according to its milestones.

The take-over date is determined at the beginning of the construction phase and is noted as the final milestone for the construction project. When the owner of the building takes over, they have formally accepted the construction project and assume responsibility for the building, including continued operation and maintenance. If the owner believes that the building does not satisfy contractual agreements and requirements, they may refuse to take over the building. Unfortunately, this happens quite often. The principal contractor has spent several years and significant resources on planning the building, dimensioning and finally building it. Why is it not working?

Increasingly Technical Buildings

In line with technological developments the world has seen over the last few decades, buildings have changed significantly. Buildings today contain a number of technical systems that communicate with each other to a great extent. The buildings have become much more complex and intelligent for both the developer and the user.

Functionality Meets Geometry – Early Testing

Traditionally, construction and technical installations are planned based on the geometry of the building. How the technical systems should be tested and operated are considered to a lesser degree. In order to achieve early testing in a project, it is important that the focus on the geometry of the building is considered in relation to how the technical systems should function, and which areas they supply. If geometry and functionality do not match, early testing will be difficult.

It is therefore important to plan the following in context:

1. Which areas should be tested/commissioned first.
2. How the technical systems are built to supply the areas that will be tested first.
3. Technical support systems serving the systems that will be supplying the areas, such as the ICT network and the BMS.
ICT (Information and Communications Technology)
BMS (Building Management System)
4. The construction sequence for areas/floors.

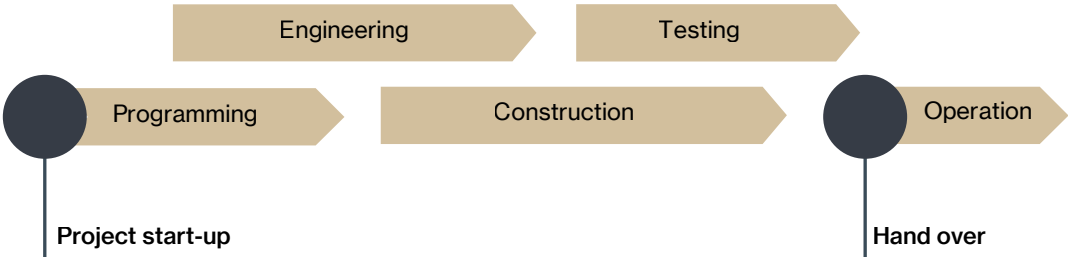


Illustration:
Traditonal project phases

Systematic completion

Definition of Systematic Completion:

Assurance that the project fulfils all functional requirements within the set requirements for time, cost and quality, planned and verified via a structured process that is management controlled from planning to takeover.

The aim is to create continuous improvement through:

- 1. Continuous focus on the result.
Geometry: Using BIM to secure the correct geometry and ensure less insecurity within the project.
Function: Plan for ensuring correct functions for all systems and integrations.
- 2. Implementation of separate work processes focusing on Systematic Completion as well as smooth and simultaneous engineering to support both the functions and geometrical solutions. Modifying the requirements for addressing and describing single and interdisciplinary issues.
- 3. Performing the work correctly the first time.

Why Systematic Completion

The construction industry must consider the technological development and the way it has affected building. When the end product has changed, it is obvious that the production of the project must also change. When technical installations constitute a larger part of the buildings than before, the technical functionalities naturally affect both planning and construction to a greater degree. This is what Systematic Completion aims to handle.

By thinking Systematic Completion, the functionality of the buildings will be considered to a greater degree. Preparing a Systematic Completion Plan early in the project enforces a focus on the technical systems and the order in which they should be built and tested. This will in turn provide input for the general plan for the building.

What is Systematic Completion

In other words, Systematic Completion does not only concern final completion, but also how to facilitate for successful completion throughout the project, with the right level of quality at the right time. The work should start when the project starts and run in iterations throughout the entire project. This requires so-called reverse planning, starting with the desired result. By defining the result early using so-called acceptance criteria, it is easier to achieve a concrete notion early on of what is required for planning, construction, and engineering. The idea is to spend more resources on planning and engineering and less resources on clarification and verification throughout the construction project due to an inaccurate foundation.

The V model below illustrates the connection between the planned foundation and testing completed systems. The illustration also shows the function of the “table tests” in terms of quality assuring the test procedures.

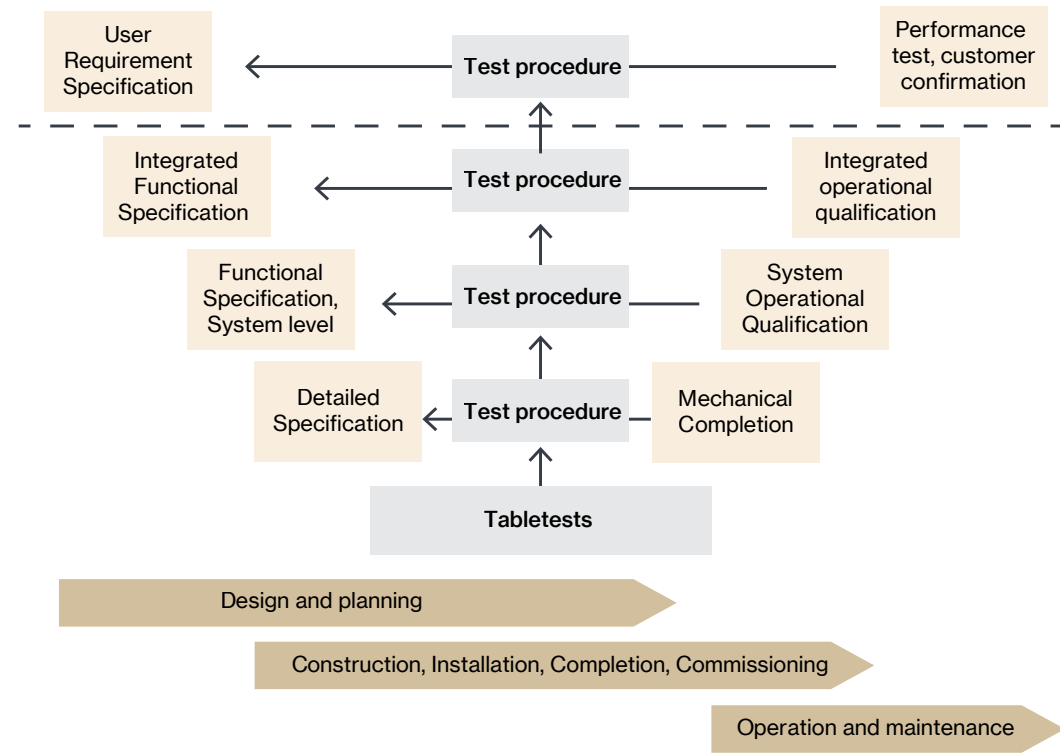


Illustration:
Connection between the engineering foundation and testing.

Systematic completion in the KHiB project

The Bergen Academy of Art and Design (KHiB) construction project has included Systematic Completion as a key process alongside processes utilised engineering, production, and procurement. This process has been allocated to a project manager.

Systematic Completion gained focus in the project after most of the planning was done. This means that much of the framework had already been established in terms of design and functionality. It was therefore important to include the parts of Systematic Completion that could still contribute to achieving the main objective of handing over a functioning building at the agreed time. The project agreed that this objective should be achieved through:

- Strict requirements for functional specifications.
- Establishing test procedures with concrete acceptance criteria for all systems.
- Testing technical systems as early as possible (step-by-step testing, commissioning) to:
- Ensure enough time for correcting any errors between testing and handover.
- Avoid building the same errors several times.
- Involving the user and operating organisation as early as possible to provide:
- Thorough training of operations personnel.
- An opportunity for input from operations personnel.

A Firm Foundation with the Stakeholders

The first thing the KHiB project did was to ensure that all stakeholders were familiarised with what Systematic Completion entails. At this time the engineering team had already been contracted, and Systematic Completion was not part of their contract. This was easily resolved because the engineering team was working on an hourly contract. Creating the foundation, therefore involved a detailed review of the process.

However, there were still no contracts established with the contractors and suppliers. A document named “Systematic Completion Requirements” was prepared and added to the tender documents. This document describes the Systematic Completion process and the requirements and expectations for the stakeholders. In that way, the contractors were provided with

information about the process before entering into the contract, and Systematic Completion was included in the rates.

Process Mentality

The KHiB project uses the Lean methodology both for engineering and implementation, and the progress planning is completed using a timetable built around processes. A process model was established for Systematic Completion illustrating the main process and several underlying levels with sub-processes.

In essence, the main process of Systematic Completion includes the following sub-processes:

- Preparation of the adopted foundation
- Several stages of testing
- Training
- MOM (MOM Management, Operations and Maintenance)

The illustration below provides a general overview of which processes linked to Systematic Completion belong in the various project phases. The test phase starts significantly earlier than what has generally been common. The next section includes a description of key terms in Systematic Completion; (adopted) foundation, testing, and training.

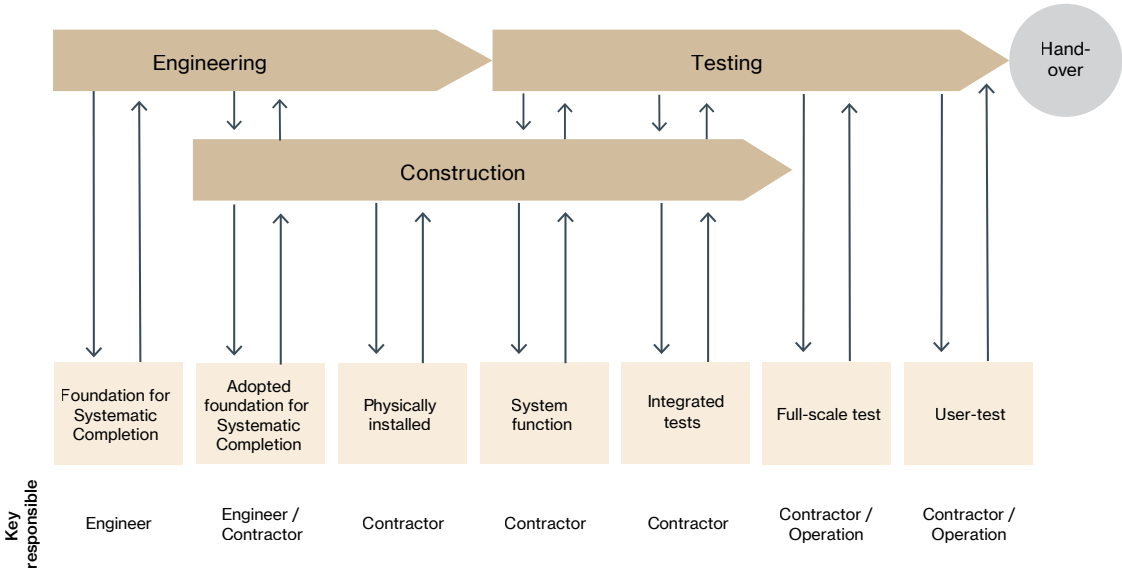


Illustration:
Phases and processes associated with Systematic Completion

The terms in the illustration on page 85 are explained below:

Documents for Systematic Completion

The documentation for Systematic Completion is prepared in the early stages and includes the following documents:

- Systematic Completion Requirements
- Systems List
- Overall Technical Infrastructure
- Test Plan

Foundation for Systematic Completion

The above documents are developed during the detailed engineering phase and are included in the call for tender. The complete foundation consists of:

- Documents for Systematic Completion (as above)
- Functional specifications
- System diagrams
- Integrated functional specifications
- Test procedures
- MOM requirements
- Training plan

The test procedures are an important part of the foundation.

Test procedures explain how a system should be tested and contain concrete acceptance criteria. The procedure is established and adopted along with the rest of the foundation.

Adopted Foundation

The foundation is adopted once engineering and implementation agree on what is being built, that the foundation is sufficient for construction, and that implementation and sub-suppliers confirm their ability to deliver what is described. It is important that the foundation is adopted well in advance of the start of construction, in order to clarify any ambiguities. It must be completed in time to complete engineering and order materials and equipment before start-up.

Table Test

Is a theoretical test around the table attended by consultants, contractors and suppliers associated with the relevant system. It may also be an advantage to include the construction manager, operations personnel and users. This must be performed before ordering equipment and components.

All systems are listed and reviewed individually or in naturally associated groups. It is possible, for example, to run a common table test for all systems in the power unit, a common test for all lighting systems, etc.

Mechanical Completion

A system is considered mechanically completed once it has been assembled with all associated equipment and components. The contractors perform self-checks, and construction management performs spot checks to ensure that the building is built according to specifications.

Area Test

Physical on-site area test. This test may be performed even if the systems have not been commissioned or completed. Examples may be IO tests or more real tests. It is performed in a chronological sequence, i.e. first built, first tested. May require actions such as blinding ducts that distribute air to areas that have not yet been built, or closing heating valves unless entire systems are being tested.

System Function Test

Physical testing of the completed system with all applicable equipment connected.

Integrated Test

Physical testing of the interaction between two or more technical systems.

Full-scale Test

Physical testing of the functionality of the building and premises with all applicable sub-systems connected.

Business Test

As the full-scale test, with all the company's equipment in normal operation.

“The 14-10-6 Process”,
A Journey Towards an Adopted Foundation

The KHiB project has been operating with a process called “14-10-6”, indicating milestones for various operations 14, 10, and 6 weeks before the first construction activity of a given system. The illustration below displays the connection between completion of the adopted foundation and the 14-10-6 process.

In practice, this means that the foundation for a system should be completed and adopted 16 weeks before system construction starts.

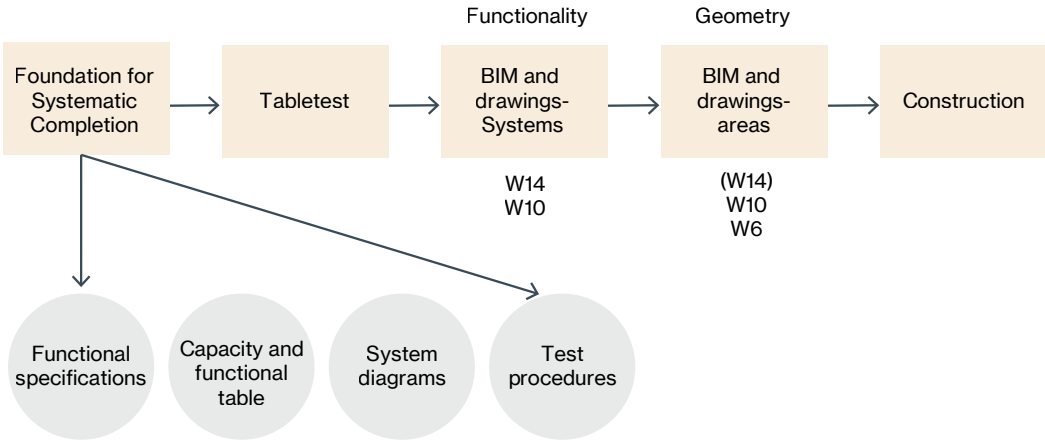


Illustration:
Adopted foundation
and 14-10-6 process

Testing and Training

In Systematic Completion, early testing and continuous involvement and training of operations personnel is a key focus point throughout the entire construction project. Illustration 5 shows the connection between testing and training in the various stages of the project.

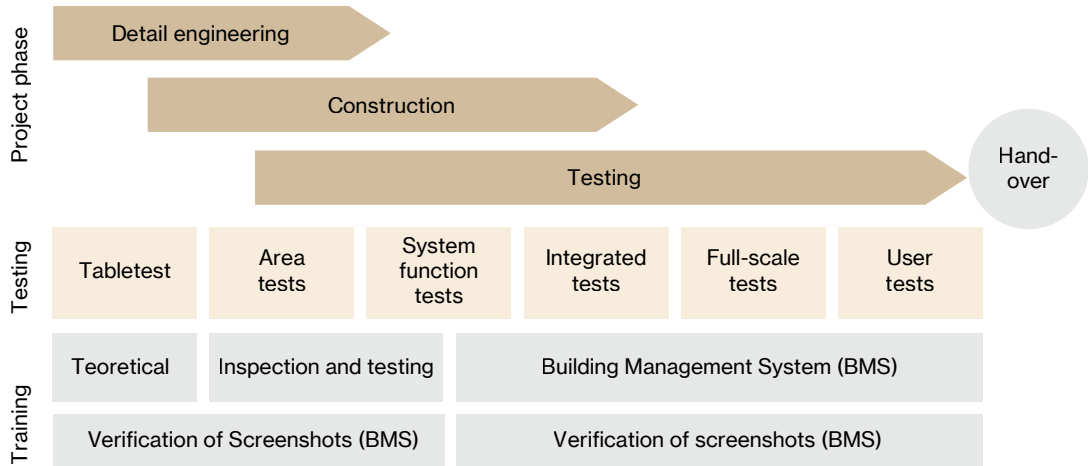


Illustration:
Connection between project
phases – tests – training



Tests

Whether or not a building is successfully completed is technically verified through testing and commissioning of the building's functionality. Traditionally, a test phase is introduced only at the end of the construction phase. As shown in the illustration on the following page, the Systematic Completion methodology prepares for testing already in the collaboration phase, the transition between the detailed engineering and construction phases. Initially the tests are all theoretical, and as the systems are completed on site, the tests become more practical.

The first thing this project did was to map out how early the first tests could be performed. The goal was to test as much as possible, as early as possible, before entire systems with associated components were built into the building. That way, any deviations uncovered during the tests could be corrected before the same deviations were built into other areas of the building. This supports the Lean philosophy's principle of continuous improvement.

Table Tests

The table tests provide an early overview of what the basis for the evaluation will be for the project upon completion and they enforce an adopted foundation prior to ordering equipment and starting construction. In order to achieve a timely adopted foundation, the project prepared a detailed plan for completing the engineering foundation (reverse planning), and the interaction between engineering and implementation. The illustration on the next page illustrates what must be completed before conducting the table tests.

"The 6-4-2 Process", A Journey from the Table Test to the Physical Tests

Like the above mentioned 14, 10, and 6-week process, the testing process has been given its own designation; "6-4-2". All tests are dated and visualised in the timetable for the KHiB project.

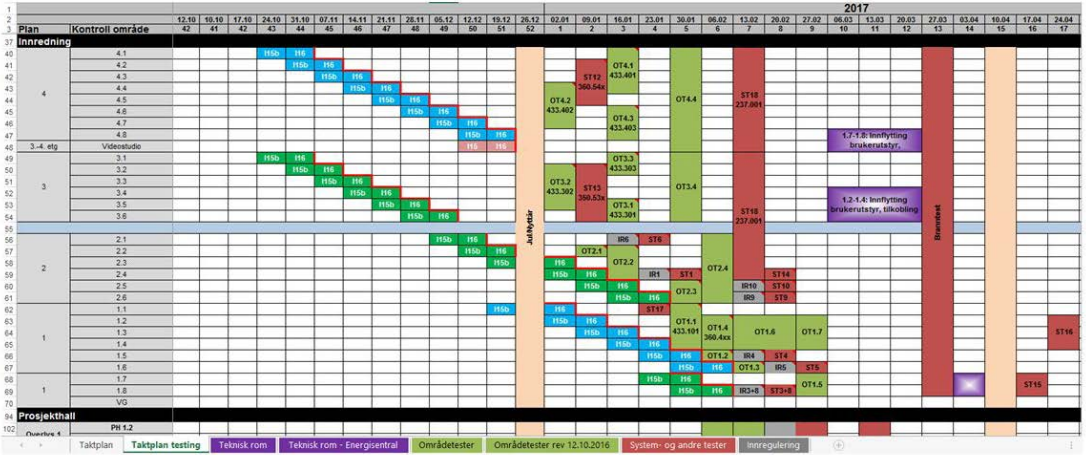
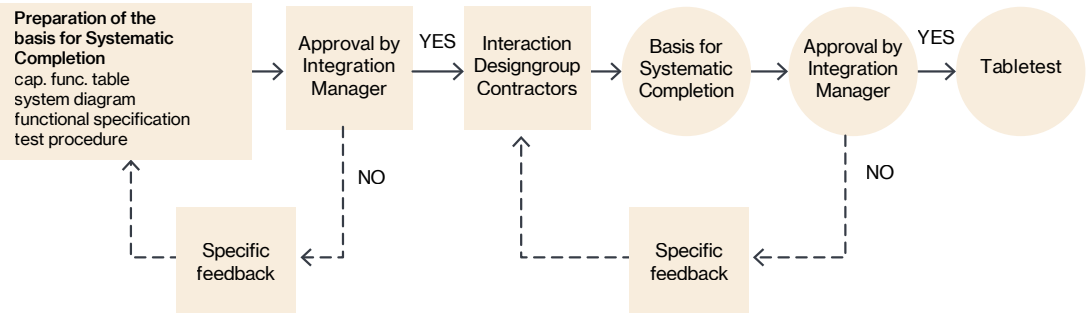


Illustration above:
The process up to the table test

Illustration below:
Excerpt from the time table showing the last two wagons and all tests

6, 4, and 2 weeks before each test, an interdisciplinary review is performed clarifying and adopting various conditions surrounding the test. The goal is to ensure test implementation and satisfaction of the acceptance criteria.

The 6-4-2 meetings are important in order to remain focused on testing. The meetings are driven by the project management. The contractors are a major driving force in the process. During the KHiB project, it became obvious to everyone involved that a common understanding of the early testing process is crucial for the success of the project.

The 6-4-2 process makes the organisation robust and flexible, enabling it to react early and handle any deviations in mechanical completion or omissions uncovered during the contractor's own testing process.

The following table displays the contents of the 6-4-2 meetings.

Attendees

Commissioning manager, project manager CON (CON Contractor), foreman (or SC if necessary (SC Subcontractor)), construction manager, integrated technical building installations responsible (ITB), project manager for Systematic Completion and operations personnel. Other attendees are decided as and when required (the right person at the right place).

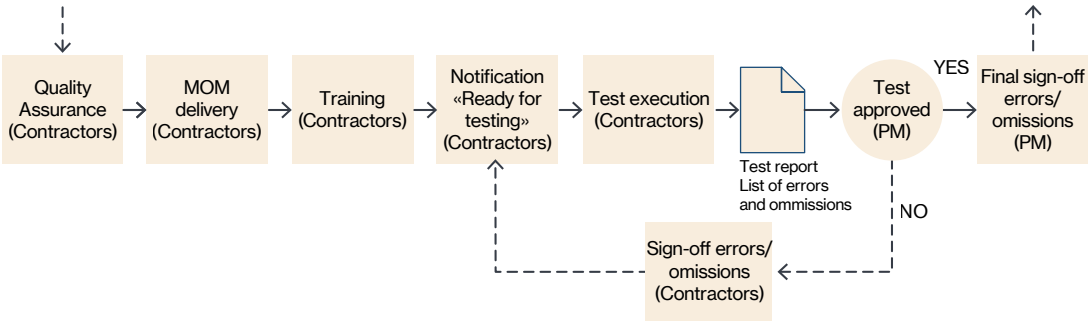


Illustration:
The test execution process

Six weeks prior to test

- Review of systems to be included in the test.
- Test procedures and functional specifications are adjusted and updated following the table test, and all items from the table test are closed.
- Plan for contractor inspection (self-check) is prepared and dated.
- Anything obstructing the test? “Deviations” from whiteboard meetings and BIM360 / mechanical completion on schedule.
- Are there any special actions to be taken in order to perform the test (limitations)?
- Conditions for contractor inspection (preparatory actions / logistics /equipment) are defined in the foundation for the test and reviewed in meetings.
- Action items and deviation from six-week meeting registered in “BIM360” (a computer based tool used in the KHiB project).

Four weeks prior to test

- Items from the six-week meeting are closed and the foundation revised, if necessary.
- Are we ready for the test? Mechanical completion on schedule?
- Preparatory actions for performing self-check and test have been planned and ordered by the contractor.
- Status review of the necessary MOM for test.
- Correct level of Clean Dry Building (CDB)?
- Safety Health Environment (SHE) in connection with performing test, resetting after test, and deviation correction.
- Mapping component training for associated systems with the operating organisation.
- Action items and deviation from four-week meeting registered in “BIM360”.
- Test invitation sent out on Outlook.

Two weeks prior to test

- Items from the four-week meeting are closed and the oundation revised, if necessary.
- Confirmation that self-check is performed and all deviations logged in “BIM360”.
- Any necessary actions for performing the test have been taken, and the necessary equipment for performing the test is available.
- The test protocol has been prepared and is ready for use.
- Test MOM complete.
- CDB OK?
- SHE review with listing of Safe Job Analysis (SJA) to be prepared connection with test execution.
- Screen shots are ready in ICS.
- Last system review in terms of what will be tested and how. Final adjustment of test procedures, if necessary.
- Review of relevant systems and any associated component training with operations completed?
- Participants have confirmed participation in Outlook.

Training

It is important that those using, operating, and maintaining the building are familiar with its functions, and comfortable with the choice of systems. Systematic Completion facilitates a significant involvement of both users and operations personnel throughout the entire construction project. This provides the project with useful input from those taking over the building, whilst also providing users and operations personnel with thorough training.

User and operations training is conducted in various arenas;

- Theoretical training sessions
- Test participation
- Practical training sessions

Once the building is completed and handed over to the owner, the building’s users and operations personnel need to know how to use it and how to run it. In the KHiB project, the building, and all its functions and equipment, will be used by KHiB, while Statsbygg EV (EV = Statsbygg Operations) will be responsible for operations and maintenance. This means that both user groups must receive training in their usage areas.

The KHiB project has divided the training into parts as shown in the illustration on the next page; one theoretical part and one physical part, both for equipment and systems, including ICS. Training is conducted partly through test participation, and partly as separate training sessions. The illustration provides an overview of the various training arenas and who should attend the various training sessions.

MOM

Statsbygg has separate procedures and systems for MOM that the KHiB project conforms to. Systematic Completion ensures the connection between the MOM processes and the training processes. The user is also involved in the planning at this stage. The second illustration on the next page displays the MOM established for the project.

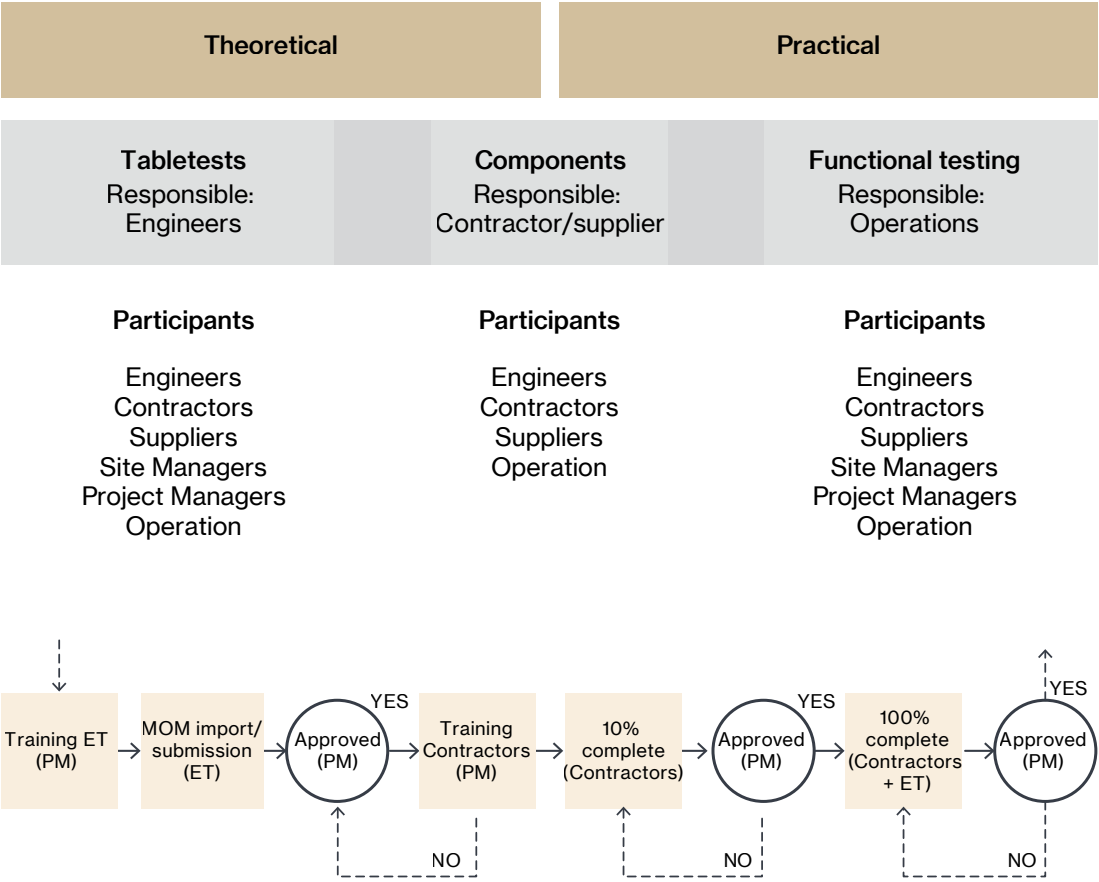


Illustration above:
Training arena

Illustration below:
MOM process in KHiB



What has the KHiB project learned

Thorough, Preventative Planning (“Front Loading”)

The idea behind Systematic Completion is to spend more resources on planning and engineering, and less resources on clarification throughout the construction project. This means that both engineering and implementation may need to allocate their resources in a different way than they are used to. It can also mean a larger scope of work for some of the stakeholders, without the reward going to the same stakeholder. Both the principal contractor and all stakeholders need to be aware of this when entering into the contract.

Change of Attitude (“Mind Shift”)

The Systematic Completion methodology requires the involved stakeholders to change their mindset. This does not mean that a generally larger scope of work is expected, but rather a greater degree of detail early on in the project in terms of planning, construction, and completion. Heavily incorporated habits are hard to change within an entire industry. The need for information, anchoring and monitoring must not be underestimated.

Involvement and Transparency

Extensive user involvement is practical both for the user and the project. Systematic Completion contributes to a broad, systematised natural involvement through tests.

A transparent system is also essential. This means that processes, activities, deadlines, and results are visible, virtual, and easily accessible (for example, notice boards). They can be equally seen and understood by everyone involved.

Table Tests

Table tests are a highly useful activity. Each table test in the KHiB project revealed unsettled issues that would have been challenging or costly to handle during construction or testing.

A table test is the final step in system engineering, not an introduction to construction. It is of great value to gather engineering, contractors, suppliers, operations, and users around the same table to discuss the functionality of the systems. Table tests should be conducted as early as possible. The contractors must therefore contract their suppliers in time

to ensure that the right skill sets attend the table tests. One example of when the KHiB project benefited greatly from this, was when a table test for the lighting control was conducted. The test revealed that the lighting control for the rooms could not be reprogrammed from the top-level system (ICS), as specified in the contract. The project solved this by changing supplier and thus fulfilling the contract.

This would not have been discovered without an early theoretical review of the functional specification with the associated test procedure and with the supplier present.

What is Next for the Project

As of December 2016, the KHiB project is approaching completion of the construction phase. All table tests have been conducted, and the next stage in Systematic Completion is the area tests. The tests are being planned in detail to ensure that they can be satisfactorily performed before the systems are completed. This includes a practical facilitation and limitation of the systems on-site.

Towards the end of the construction phase, integrated tests, full-scale tests, and business tests will be performed as a final verification that the systems are working together during normal operation.

Lean Construction



Lean construction

The KHiB-project has had as an objective to be a role-model in the use of Lean. Early on, thorough planning was made of both the work foundation and the work execution. This was made to minimise the typical errors that traditionally occur in a construction project and to be proactively ahead of them. To achieve a correct foundation, much time was made available during the detailed design phase. In this project, Statsbygg, as the owner, chose to execute takt planning (see below) of the entire construction phase prior to sending out the tenders. The working taktplan was attached to the tender, but it was not a complete version. The intention was that the contractors after signing were to participate in the Lean collaboration stage to complete the plan and make it final.

A block of topic-related meetings on the construction site enabled everyone to go through all activities and make them as sound as possible. They were called «14-10» and «6-4-1», which intends to define a given number of weeks prior to the start in a defined control area. The 7 conditions for a sound activity (see below) were reviewed, from a more top-level perspective («14-10») and from a more specific perspective prior to production («6-4-1»). The construction site followed up with amongst other the use of BIM-kiosks (see below) and daily status meetings at the taktboards (see below).

The experiences from takt planning in the Lean collaboration-stage are that contractors, subcontractors, and suppliers of complex and advanced equipment, must be involved very early in the planning. It is the foremen who have the best knowledge of how to perform the work. They understand best the dependencies, the correlations, and the amount of work required for the different work operations. This influences to a greater degree the quality of the taktplan. The project has further experienced that the taktboards need to be continuously adapted during the construction phase. They need to be flexible.

In the opinion of the KHiB-project, implementing Lean construction and takt planning provide huge opportunities. There is great potential for higher revenues, better quality, and increased productivity by being more thorough in the planning stage.

Takt planning

In the production industry, the product moves effortlessly from one station to the next, on its way to the final stage. In the construction industry, the product for obvious reasons can't be moved. So, to obtain a natural flow, a steady increase of added value, the process has to be moved instead.

Much time and effort has been invested to prepare and obtain the optimal work-progress-plan. Much thought, consideration, and coordination has been put into the scheduling of tasks and the availability of skills and materials to ensure that the work progresses as smoothly as possible. The outcome is the «Taktplan». This plan is still an unusual way to schedule tasks and visualise all work operations. Yet the plan is also a very easy, systematic, and structured way to show all construction works on a single, easy-at-hand overview. The taktplan and some of the connected terms are explained further on the following pages.

Control area

A control area is a specifically designated area where the work will be performed. The work for a control area is described in detail. Control areas can vary in size depending on the complexity of the area. On the KHiB-project they were about 400 sqm. However, each control area on a project should require a similar amount of workload to be consistent with the takt (see below). As far as possible only one trade should be present per week in one control area.

«Train» (Parade of Trades)

The natural sequence of operations (activities) needed to complete a control area, is normally called a process. In the KHiB-project, the word process has been renamed to the word train. It is also known under the name Parade of Trades. Activities in the train are described in detail trade by trade (see «Wagon»). All trains for every area within the construction project are further described separately. In this chapter the trains for interior works, landscaping, the project hall, and the technical rooms are illustrated. (The illustrations give a visualisation of the detailed planning. Please note, the text remains in Norwegian.)

«Wagon» (Trade)

A train consists of many activities that naturally travel through a control area one after the other. These activities are called wagons, and a wagon contains a set of tasks. A wagon should basically consist of one trade only, but some wagons can, for

practical reasons, also contain several trades, depending on complexity and trade size. There is, however, always only one defined trade who has the responsibility for the wagon.

Takt (Rhythm)

In the KHiB-project a wagon has a duration of one week. This sets the project's beat, which is the steady rhythm in the construction progress, in which the production moves forward. The workload must be calculated and planned in detail to achieve the best possible rhythm, which again will obtain the best possible production flow. The KHiB-project has a large number of different control areas, varying in both complexity and size. Consequently the amount of work has differed from area to area, the non-repeatable areas. To preserve the smoothest possible rhythm (flow) throughout the whole construction phase, the number of crew, therefore, has varied from week to week in the same wagon. In construction projects containing a large number of repeatable areas, same size same workload, the crew can remain much more even.

Taktplan

The taktplan is the combined result of the above four elements. It is a detailed overview of all operations in the construction project set out on a single poster. The connection between control areas, trains, wagons, and takt can be clearly visualised.

Photo: Tomasz Majewski



Taktplan

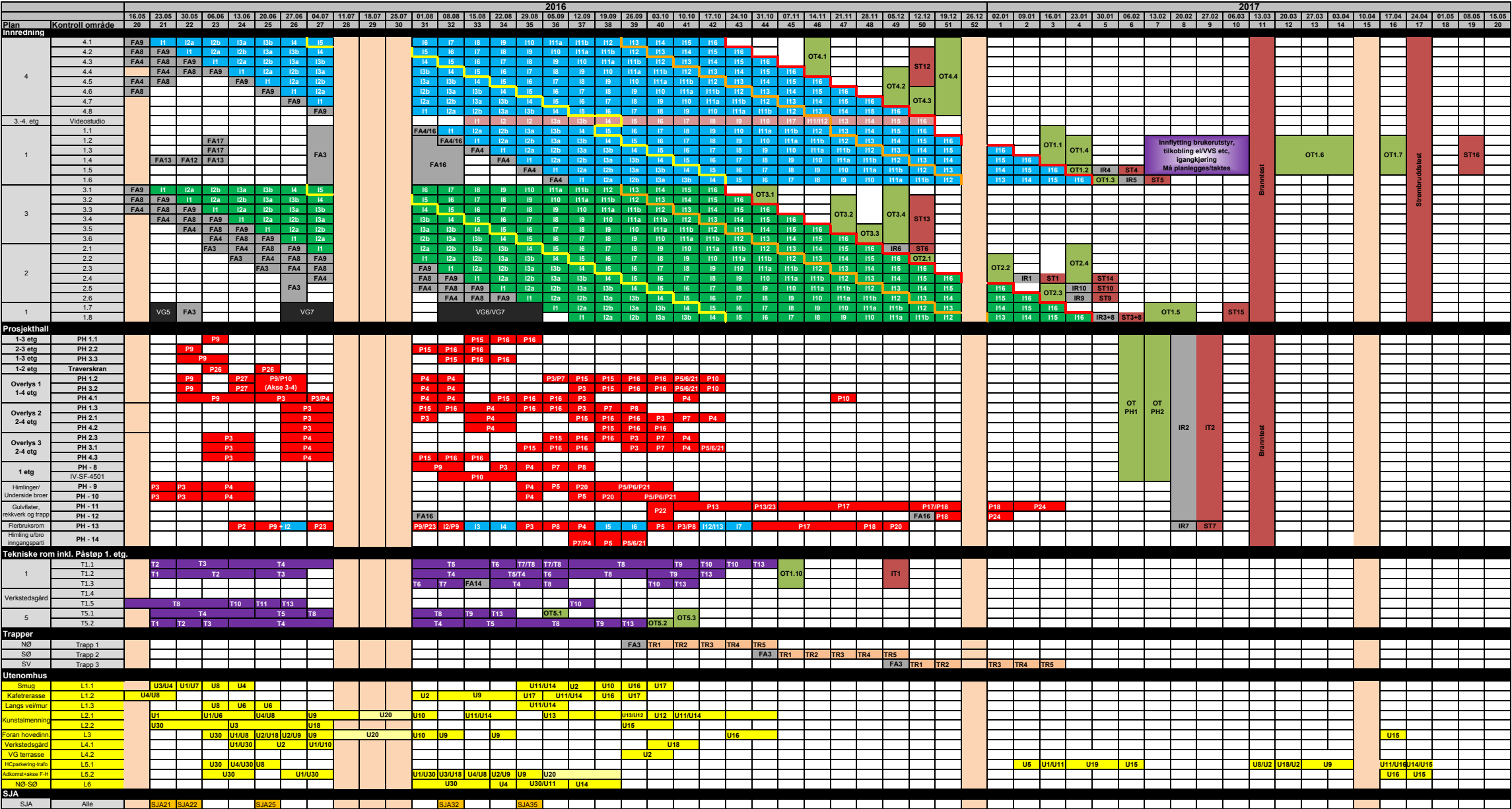
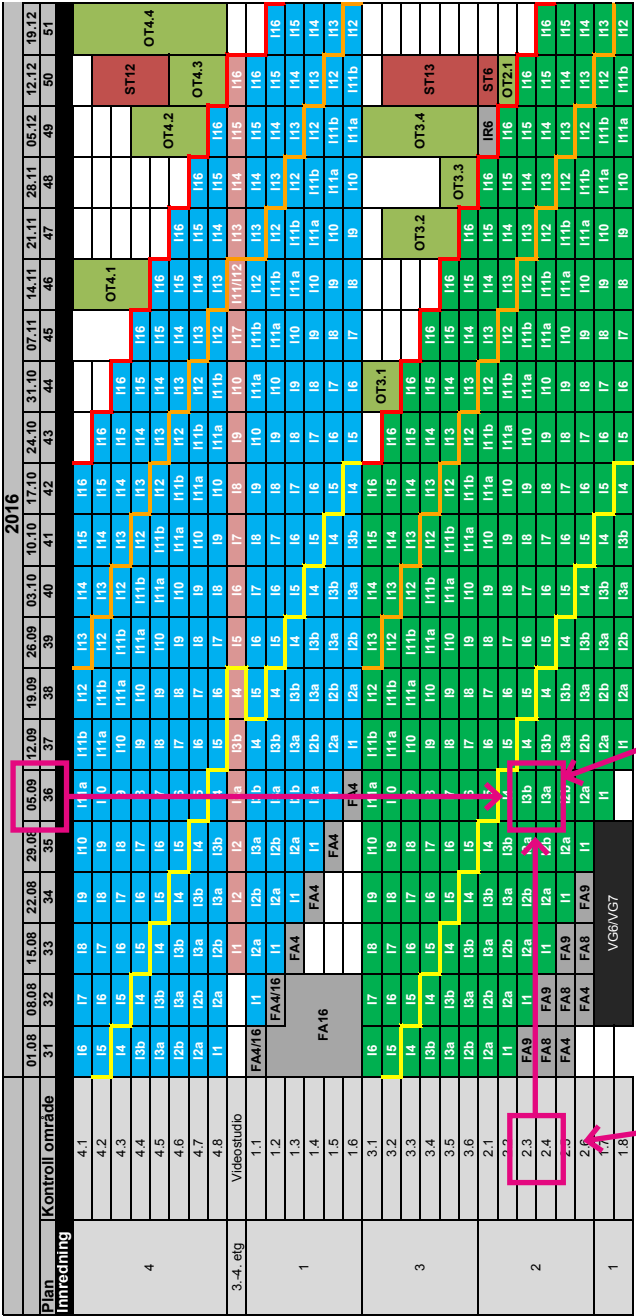


Illustration:
The KHiB project taktplan

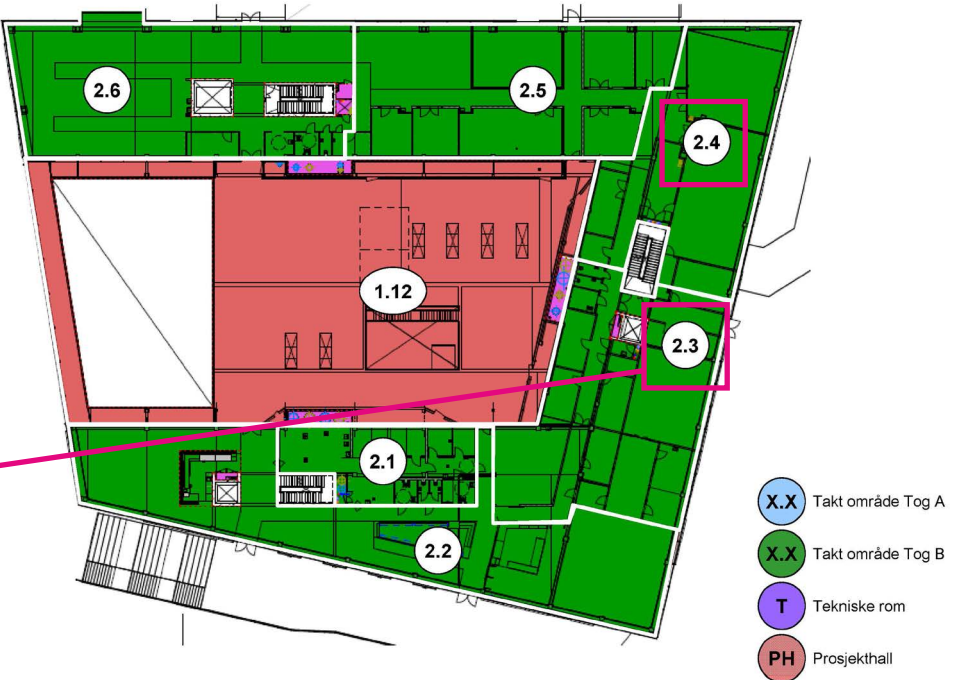
How to read the Taktplan

Illustration:
The connection between the
taktplan, trades (activities)
and control areas



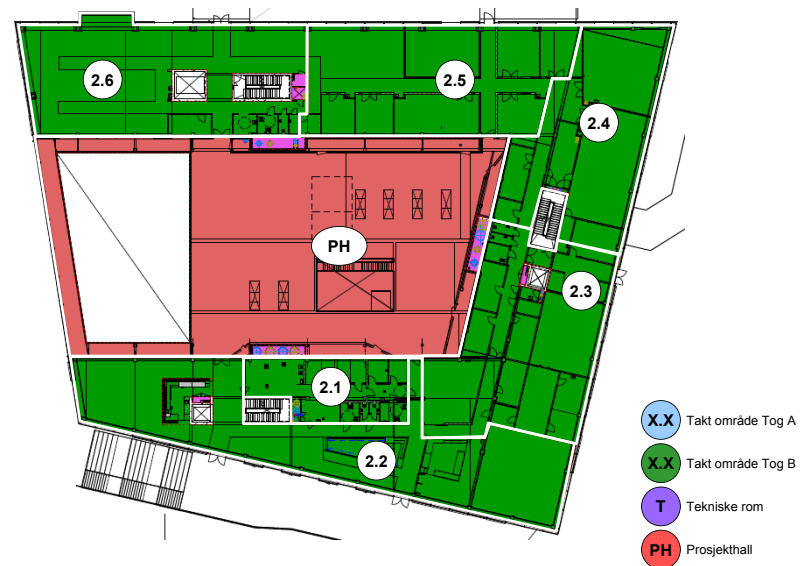
Innredning						
Entreprise	Fag	Arbeidsoperasjon	Vogn Tog A	Vogn Tog B	VOGNEIER	
					BL	Kxxx
K206	Påstøp	Isolering overkant hulledekk inkl. plastfolie Armering Randisolering og fugging Påstøp Sliping og oljing Tildekking av betonggulv Eventuelt: slissing/lydfuge	I1	I1	BLB1	K206
K206	Tømrer	Brannisolering og brannmaling av stålsøyler og glitterdragere Stålstender påforing 70mm mot fasadeelementer og mot Prosjekthallvegg Stålstendere innervegger Enkling av innvendige vegger, inkl utsparinger Foring av smyg dører (systemvegger) Foring av smyg vindusutsparinger Spikerslag for tunge installasjoner vegg	I2a&b	I2a&b	BLB1	K206
K206	Maler	Maling av hulledekk, i spesielle rom	I3a	I3a	BLV	K301
K204	Blikkenslager	Innvendig beslag i karnapp.	I3b	I3b	BLE	K401
K204	Murer	Montering av avløp og overvann i vegg	I4	I4	BLB1	K206
K301	Rørlegger	Montering av avløp og overvann i vegg				
K401	Elektriker	Montering av el-boks og trekkerør for svakstrøm og sterkstrøm i tak og vegg				
K302	Ventilasjon	Montering av ventilasjonskanal i vegg				
K401	Elektriker	Montering av el-boks og trekkerør for svakstrøm og sterkstrøm i tak og vegg				
K206	Tømrer	Oppbygging av gulv i karnapp. Isolering av innvendige vegger Dobling av innvendige vegger inkl lukking av 70mm påforingsvegger Lydfuge mellom vegg/tak og vegg/gulv				

Plan 2



Takt control areas

Plan 1-2:



Plan 3-4:

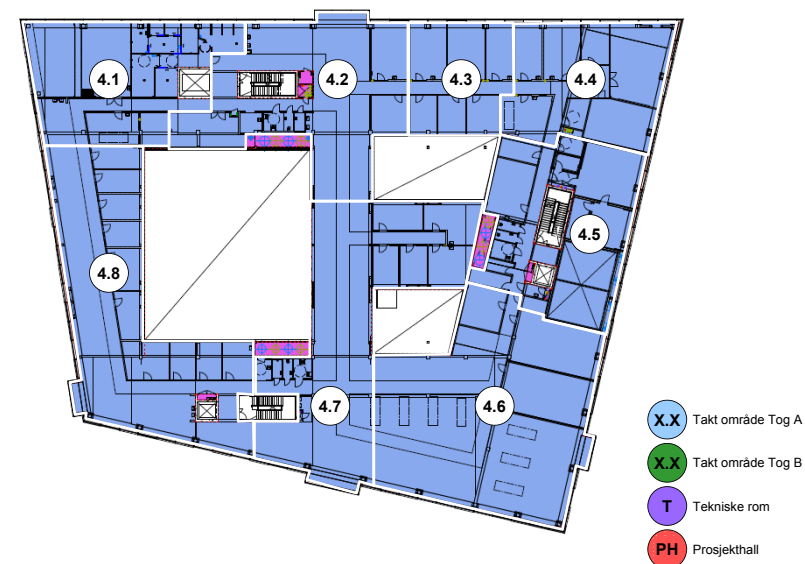
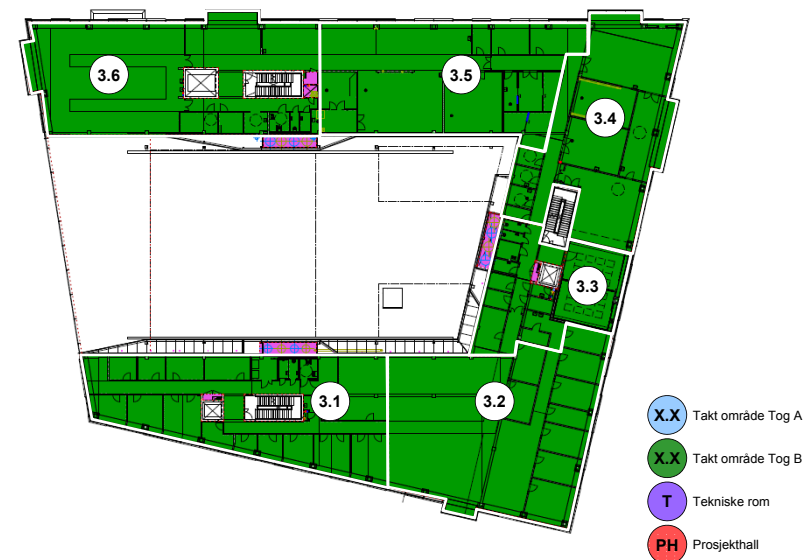


Illustration:
The KHiB project takt control areas

The Train

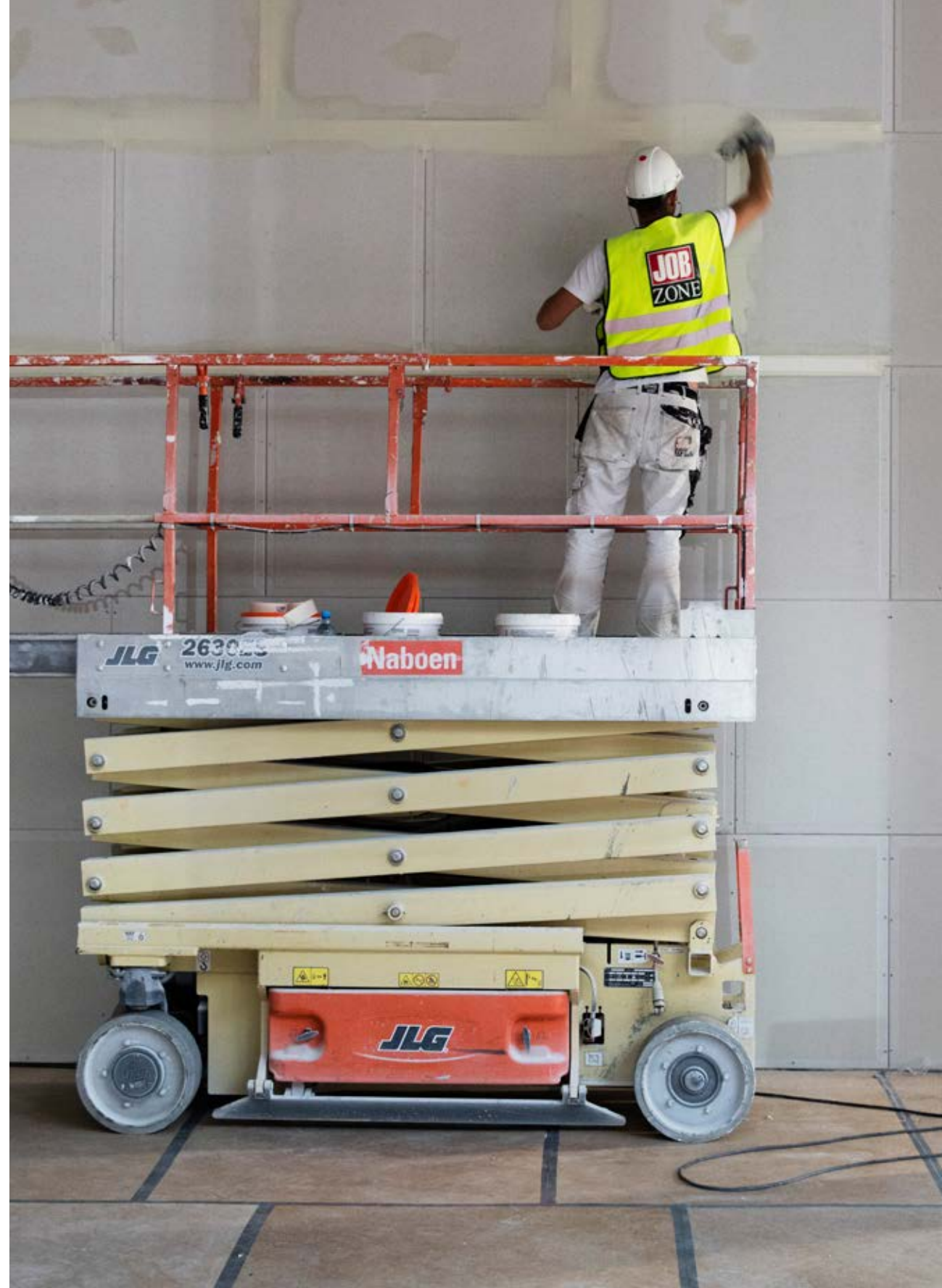
“The Parade of Trades”

Innredning						
Entreprise	Fag	Arbeidsoperasjon	Vogn Tog A	Vogn Tog B	VOGNEIER	
					BL	Kxxx
K206	Påstøp	Isolering overkant hulldekke inkl. plastfolie	I1	I1	BLB1	K206
		Armering				
		Randsisolering og fuging				
		Påstøp				
K206	Tømrer	Sliping og oljing	I2a5b	I2a5b	BLB1	K206
		Tildekking av betonggulv				
		Eventuelt: slissing/lydfuge				
		Brannisolering og brannmaling av stålsøyler og gitterdragere				
K206	Maler	Stålstender påforing 70mm mot fasadeelementer og mot Prosjekthallvegg	I3a	I3a	BLV	K301
		Stålstender innrigger				
		Enking av innvendige vegger, inkl utspæringer				
		Foring av smyg dører (systemvegger)				
K206	Blikkenslager	Foring av smyg vindutsparinger	I3a	I3a	BLV	K301
K204		Spikerslag for tunge installasjoner vegg				
K204		Maling av hulledekk i spesielle rom				
K301	Rørlegger	Innvendig beslag i karnapp	I3b	I3b	BLE	K401
		Membran bak toalett sistene				
		Installasjon av stålrammer for vegghengte toaletter				
		Rør-rør fra fordelerskap til utstyr - inkl koblinger				
K401	Elektriker	Montering av avløp og overløp i vegg	I3b	I3b	BLE	K401
K302		Montering av el-boks og trekkerør for svakstrøm og sterkstrøm i tak og vegg				
K401	Elektriker	Montering av ventilasjonskanal i vegg	I4	I4	BLB1	K206
K206	Tømrer	Oppbygging av gulv i karnapp				
K206	Maler	Isolering av innvendige vegger	I5	I5	BLB1	K206
K206		Dobling av innvendige vegger inkl lukking av 70mm påforingsvegger				
K206	Maler	Lydfuge mellom vegg/tak og vegg/gulv	I6	I6	BLB1	K206
K206		Sparking og pussing av fibergips-vegger				
K206	Tømrer	Grunning/porsifisering av fibergips-vegger	I7	I7	BLB1	K206
K206		Maling av fibergips-vegger (2-strøk)				
K301	Rørlegger	Akustiske plater vegg, inkl	I8	I8	BLV	K301
		Direktemontert akustisk himling inkl. isolasjon, spikerslag, beslag				
		Montering av opphengstag for akustisk himling samt wire for baffelskinner				
		Montering av uinstrut-skinner (korridor)				
K401	Elektro	Montering av avløpsrør og evt. isolering	I9	I9	BLV	K302
K302		Montering sprinkler rør, korridor og rom				
K501	Automasjon	Montering sprinkler hoder	I10	I10	BLV	K301
K401	Elektriker	Montering aspirasjon				
K301	Rørlegger	Installasjon av ventilasjonskanaler	I11a	I11a	BLE	K401
K401		Installasjon av tilføts-/avtrekksventilator				
K501	Automasjon	Isolering ventilasjonkanaler	I11b	I11b	BLE	K401
K401	Elektriker	Levering av utstyr				
K301	Rørlegger	Montering av uinstrut-skinner under ventilasjonskanaler(korridor)	I12	I12	BLE	K401
K501		Montering av KV og VV, hovedføringer og i rom og evt. kjøling				
K401	Elektro	Isolering av KV og VV og evt. kjøling	I12	I12	BLE	K401
K301		Montering trykkluft, hovedføringer og inn til rom				
K501	Automasjon	Montering av varmepanel tak inkl varmerør	I13	I13	BLB1	K206
K401	Elektriker	Isolering varmerør				
K401	Elektro	Trykktesting av alle rørsystemer i takområde	I14	I14	BLB1	K206
K501		Levering av utstyr				
K401	Elektro	Installasjon av kabelføringer	I14	I14	BLB1	K206
K501		Feste for kabeltrommel				
K401	Elektro	Kabel trekking, lavspenn	I14	I14	BLB1	K206
K501		Kabel trekking, lys og nedlys				
K401	Elektro	Montering av tavle	I14	I14	BLB1	K206
K501		Kabel trekking, lys og nedlys				
K401	Elektro	Kabel trekking IKT	I14	I14	BLB1	K206
K501		Kabel trekking for BUS				
K401	Elektro	Montering av tavle	I14	I14	BLB1	K206
K501		Kabel trekking for brann- og alarmsystem				
K401	Elektro	Kabel trekking IKT	I14	I14	BLB1	K206
K501		Kabel trekking AV-system				
K401	Elektro	Ferdigstilte installasjoner, inkl sol-, og komfortavskjerming, blending, merking	I14	I14	BLB1	K206
K501		Komplettering av brytere og uttak				
K401	Elektro	Montering av deksel	I14	I14	BLB1	K206
K501		Rengjøring over himling				
K401	Elektro	Montering sekundærbæring akustisk nedsenket himling	I14	I14	BLB1	K206
K501		Montering av akustiske himlingsplater inkl tekniske installasjoner.				
K401	Elektro	Montering av ventilasjonsventilator i nedsenket himling	I13	I13	BLB1	K206
K501		Komplettering 52, 54, 56 og kamera.				
K401	Elektro	Montering av lys	I13	I13	BLB1	K206
K501		Montering av akustiske baffer				
K401	Elektro	Montering screen i karnapp	I14	I14	BLB1	K206
K501		Montering innvendig rekkverk i karnapp				
K401	Elektro	Montering innvendig screen i vinduer	I14	I14	BLB1	K206
K501		Montering gulvbelegg inkl. oppkant på vegg og vinyl på vegg + klemning på sluk				
K401	Elektro	Beskyttelse gulv	I14	I14	BLB1	K206
K501		Montering av gulv				

Illustration:

A section of The Parade of Trades
from the KHiB project interior works
(untranslated)

Photo: Statsbygg
Trond Isaksen





Early preparations

Much is planned and prepared before the teams starts to work in a control area. Construction is almost the last thing to be done, and it should progress as smoothly and rationally as possible. In the KHiB-project the taktplan is the basis for all activities. When planning the starting point for the early preparation of the activities, one counts a defined number of weeks backwards in time from the week a task is to be carried out.

Below we find some of the many activities undertaken in the preparation and planning ahead of the KHiB-construction.

«System»: 14–10 weeks prior to start

In the 14-10-meeting complicated designs and complex dependencies are debated. Multidisciplinary challenges are considered by the team and solutions are carefully scheduled. This includes making decisions for products with long lead times («LLI») so that they arrive on the construction site at the right time. The level of detail is basic. Participants in the meeting are primarily the designers, but also contractors with their subcontractors and specialised suppliers. In the KHiB-project the owner chairs the meeting.

«Production»: 6–4 weeks prior to start

Issues from the 14-10-meeting must be clarified and closed before moving into the 6-4-meeting. Weeks 6-4 before construction in a given control area, multi and single disciplinary dependencies are discussed and coordinated, and technical and practical issues are planned and resolved. The level of detail is now high. Participants in the meeting are primarily the contractors with their subcontractors and specialised suppliers. Also the designers participate. In the KHiB-project the owner, represented by the site management, chairs the meeting.

BIM model walk through

The walk through is held four weeks prior to the start of production in any given control area. The KHiB-project has used Solibri, a digital tool illustrating the building in 3D. By using the 3D model the team discusses, coordinates, and clarifies the construction and technical challenges area by area. The level of detail is high and focusing on practical solutions. Participants in the meeting are primarily the various foremen together with the designers. The meeting is chaired by the BIM Site manager (a separate role).

Logistics Meeting

The meeting is held on a weekly basis, one week prior to the start of production in any given control area. Logistics and transportation requirements must be registered 3-4 weeks in advance. All deliveries are registered and confirmed, and transparent logistics and delivery plans are prepared for every floor. The solutions should create optimum flow for the whole of the construction site. The level of detail is high and focusing on practical solutions. Special issues are to be highlighted in the 6-4-meeting. All relevant contractors and their sub-contractors and suppliers participate. The meeting is chaired by the Logistics manager.

Foremen Meeting

The meeting is held 6, 4, and 1 week prior to the start of production in any given control area. The participating team discuss, coordinate, and clarify the construction, multidisciplinary challenges, and technical challenges. The level of detail is high and focusing on practical solutions. All relevant foremen participate. The meeting is chaired by the relevant main contractor.

«Ready to start»: 1 week prior to start

This meeting is a signoff of the 7 conditions for a sound activity. Issues from the 6-4-meeting must be clarified and closed before moving into the Ready-to-start-meeting. The meeting is held by the foreman and his work crew one week prior to start in any given control area. With one week as the chosen takt, the effective production should start on Monday morning.

«Geometry»: Full-scale Test room

A full-scale room («mock up») is built in accordance with the real-time takt of activities for the interior work. This enables site managers, contractors, and designers to test, verify, and adjust the planned order of activities. Valuable experience is achieved. Construction errors can be discovered and eliminated. Quality can be assured.

«Function»: Table test

The KHiB-project has also implemented a system of «table tests». A table test is a theoretical walkthrough of all the technical systems in the building, starting with the feature description and the final test procedure of any given system. A table test is a theoretical version of the functional test, and it must be carried out whilst completing the design work. Participation in the meeting depends on the system being tested. The meeting attendees are designers, relevant contractors, relevant suppliers, site management, operating personnel, and users.



The 7 conditions for a Sound Activity

All of the 7 conditions for a sound activity must be fulfilled before starting in a new control area (on Monday morning). This ensures the most efficient start of any activity. The same 7 conditions must also be fulfilled 4, 6, 10, and 14 weeks before starting in any control area. However, the conditions are then seen in a wider perspective. The 7 conditions for a sound activity are explained below.

1. Prior activities

Prior activities are completely finished and have the required quality. The next activity entering an area first verifies the readiness of this area together with site management and the activity exiting the area.

2. Construction Design and Information

Drawings, foundation, BIM models, and other required information is available. It also safeguards the quality, health and safety. The construction design is at the right level of development.

3. Materials and Components

Materials and components are of the right quality and the right amount at the right place to the right time. The workers have checked that the materials and the components fulfil the requested descriptions.

4. Workers

The workers have the right knowledge and capacity. They have fully understood the tasks to be performed. Necessary changes have been considered in advance.

5. Equipment

Equipment needed to perform the task is available. The equipment is appropriate, safe, and tested. Protection gear is available, and cleaning equipment is easily available.

6. Workspace and Safety

Ensure that the workspace, and the areas around are tidy and prepared. Safe job analysis (SJA) has been held and implemented.

7. External Conditions

Approvals and permissions are given. This condition also includes measures to counteract weather conditions.

Photo: Snøhetta
Astrid Renata Van Veen



Taktboard Meetings

Why

The base for the construction site progress is the current version of the taktplan. The daily taktboard meetings check and confirm the status of the progress. The meeting should be brief. The meeting should give a up-to-date description of the control area. Any deviations and possible errors needing adjustment are registered as issues and followed up by an appropriate person. This enables coordination across the different areas in the building.

Topics

In the KHiB-project, five selected topics were discussed in the taktboard meeting:

- Health and safety
- Quality
- Tidiness, CDB = CLean Dry Building
- Progress
- Staffing.

Any deviations and possible errors needing adjustment are registered as issues and followed up by an appropriate person. The appropriate responsible person solves the issue within a given timeframe. Every Friday the next activity entering an area first verifies the readiness of this area together with site-management and the activity exiting the area.

Participants

Site manager, contracting manager, subcontractor, supplier, and foremen participate in the meeting depending on the activity in the control area. Additional resources from the control area participate as needed.

When / Duration

Taktboard meetings are held daily at specified boards for each control area. The meeting should be brief, usually not more than 15 minutes. In the KHiB-project the taktboard meetings for all the different control areas took place between 12:00 to 13:45.

Experience from the project tells us that the handover from one trade to the next in each control area must be clarified and be part of the taktboard meeting.



BIM@KHiB

Brief information about BIM

The letters BIM stand for:

B = Building

I = Information

M = Modelling (the process) or Model (the product)

BIM can be used and referred to as both a process (for modelling) and a product (the model itself). It is also possible to link information in anything from three to (at least) six dimensions, generally termed 3D (length, width, height), 4D (+ time), 5D (+ cost), 6D (+ life cycle), etc.

In the BIM model, all the desired information can be linked to the drawn objects together with information on the construction project in one place. This simplifies information flow, information exchange, and communication between all participants in the project. The room and all elements of a room are designed from all sides. BIM can be utilised during design, construction, and operations.

As far as design is concerned, the purpose of BIM and digital interaction is to achieve better information flow across the different disciplines, both internally in the design group, and between the design group and all contractors and suppliers involved. The focus in the KHiB project was on optimising BIM as a tool in the design and construction process, and the widest possible use of the BIM model as a basis for construction in the execution phase.

The structure of the BIM model must be based on open, international standards. As the client, Statsbygg's goal in using BIM is to increase the usefulness of its own buildings for operating personnel (facility management), tenants and users alike. In using BIM, it should be possible to reduce defects and damages that typically occur in the construction phase or during operations. In the KHiB project, the BIM model was developed and enriched continuously from design through to completion and handover. After completion of the construction project an «As-built» model was handed over to the facility management department for further enrichment with MOM information. (MOM = Management, Operation, and Maintenance) MOM information had also been collected systematically in close collaboration with the facility management during the design and construction phases.

Information exchange in BIM

During the detailed design and construction, the design group worked in the same software (Revit) and on the same server (Revit server). With continuous access to each other's discipline models, everyone is able to keep up to date with the most recent documentation produced. The models are also collated in a shared format (IFC) that has been made available to everyone, including participants who are not part of the design group (open BIM). The design group co-locates regularly: three days every other week and one day in the intervening week. The three-day meetings are held with a fixed agenda that includes working meetings, information exchanges, and a joint review of the IFC model.

The design personnel show mutual trust by granting each other access to their models (ARCH, EL, HVAC, etc.). The technical consultants for electro, fire, and acoustics have access to the architect's Revit model, for example. This means that they can enter relevant values and suitable parameters for walls, doors, and glass partitions, themselves. This avoids errors resulting from the manual transfer of data between drawing and model.

The Revit model communicates with several support programs, such as the room database dRofus, the door environment software Microbuild, and the technical information database TIDA. The information linked to the project's many doors, for example, is synchronised between Revit and Microbuild on a regular basis. (Among other things, Microbuild includes a fittings and production list for doors.) During production, the contractors have access to Microbuild too, and they enter supplier information and production status. This information is then synchronised back to the ARCH model.

In the architect's model, all the building components and all equipment (objects) are synchronised with the room database dRofus. dRofus assigns the objects a unique TFM number (Tverrfaglig Merkesystem = cross-disciplinary labelling system). These numbers are transferred back to the ARCH model for use in MOM, i.e. management, operation, and maintenance of the building. All the MOM documentation is produced on the basis of the information contained in the BIM model. It is then transferred to TIDA. TIDA is directly linked to the BIM model via a plug-in in Revit. In this way, the content is synchronised back and forth between the model and the TIDA database.

BIM sessions / clash detections

The KHIB project drew up a BIM implementation plan. The plan provided guidance on who had which responsibilities and to how the models were to be constructed, exchanged, and handled in day-today operations.

Requirements and deadlines for all the designers with regard to uploading their discipline models (Revit to IFC) were set ahead of the BIM sessions during the co-locations. All the individual IFC models were then collated and made available in the Solibri software (Solibri Model Viewer). The Solibri model was then uploaded to the project's web-based project hotel (IT Base) so that everyone with access to the models could open it using either the free or the paid-for version of Solibri. During the construction phase, the Solibri model was collated on a daily basis and made available on the construction site in the BIM kiosks (see below).

Using the Solibri model as a basis, clash detections were carried out at each three-day co-location. The clash detections were performed using specially adapted detections rules. The detections were summarised in reports specifying who was to rectify the clash detections and how. The reports were generated in BCF (BIM Collaboration Format), an open format that can be imported and read directly in Revit. The model was used continuously for visualisation and crossdisciplinary interaction in both the design and the construction phase. Little use was made of paper drawings in the construction phase.

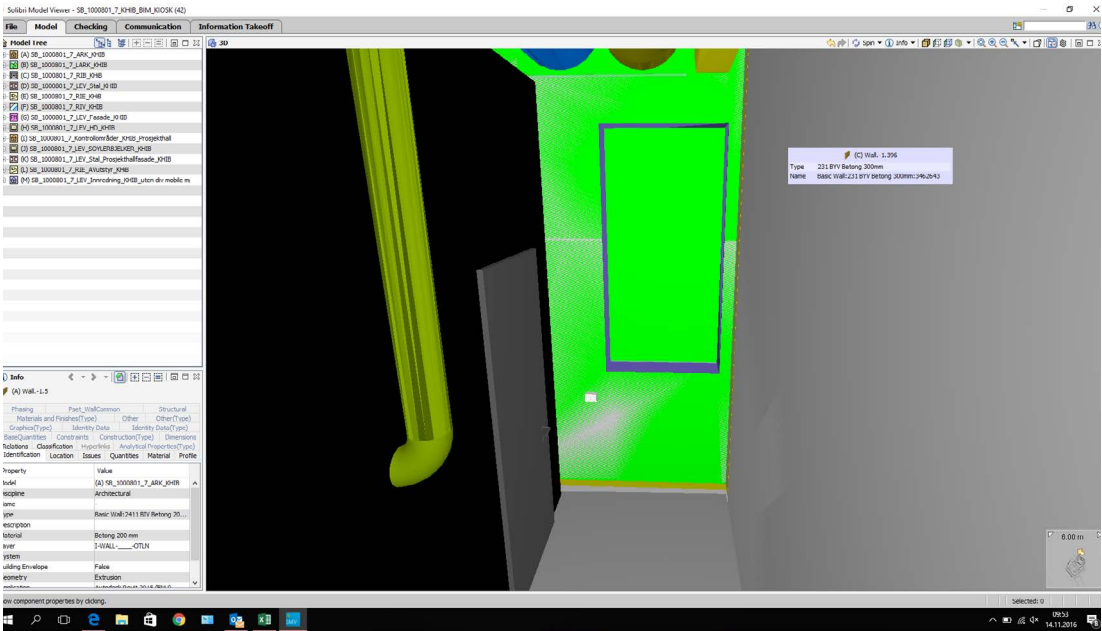


Photo: Snøhetta
Astrid Renata Van Veen

Illustration: Snøhetta
BIM model



BIM in supplier design

In the shell phase, BIM supplier design was carried out for prefabricated concrete beams, prefabricated concrete pillars, steel, and hollow-core floor slabs. Set requirements for the suppliers' deliverables were communicated in requests for tender so that the suppliers were geared up and prepared for the work at an early stage.

The building's façades were designed in the form of prefabricated sandwich elements with surface-mounted cassettes. The façade took the form of a separate contract for which full use of BIM was required. The supplier took over the architect's façade model at conclusion of the contract. In practice, however, the architect and the contractor shared the modelling work. Owing to the stringent requirements for accuracy at the interface between the shell (floor slab front edges) and the façade elements, all the details and transitions were modelled true to shape. The installation work was completed as planned.

Modelling of the solutions from supplier design at the interface with the design group's models was defined as the responsibility of the contractor. Problems and questions identified by the contractor were communicated to the design group by means of separate BCF reports. In the KHiB project, the BCF reports were mainly used for one-way communication, i.e. as straight reports to the design group. In other cases where use was made of the format's feedback options, this worked well too.

Looking back, experience shows that coordination could probably have been made easier if dedicated cloud solutions had been used for communication and BIM. The KHiB project also opted to have just one Solibri model for everyone to use for viewing and reading information. This solution can give rise to logistical challenges because there can be no parallel clash detections or collations.

BIM on the construction site

BIM kiosks offer great benefits in terms of digital interaction. A key premise when setting up BIM kiosks is mobility. The mobility of the kiosks ensures optimum accessibility for all ongoing work in the building. During the KHiB project's shell phase, the BIM kiosks were used the most by the people working on the reinforcement. In a project with a lot of prefabrication, ordinary drawings will also provide the necessary information. For straight installation work on pillars, beams, hollow-core floor slabs, and steel, therefore, supplementary information from the BIM would not necessarily have the same utility value.

The kiosks for the KHiB project were built in situ and based on a powerful laptop computer and large screen. During the shell phase, the kiosk was set up in a movable 8' container. During the fitting-up phase (interior constructions), the kiosks were installed in a plywood enclosure mounted on wheels. This solution was much more mobile than the container solution used in the shell phase.

The KHiB project configured the BIM kiosks in such a way that they automatically downloaded updated models from the web hotel to the construction site's network. The BIM coordinator can at any time check via email that updates have been carried out and that the kiosks are online. (In the KHiB project during all construction stages, the BIM coordinator was either a resource from the design group or the dedicated BIM site manager. See next section.)

Good web access on the construction site is an important prerequisite. Setting up the building site network proved to be more demanding than anticipated, and it was a long time before it worked satisfactorily. Mobile data solutions might be a good alternative. (New technical solutions are continuously being developed.) The BIM kiosks on all floors of the construction site were set up with wireless connection, which works well as long as care is taken to ensure an almost 100% coverage. Automated updates for the BIM kiosks would simplify their operation.

Data export from the design software has to be organised in such a way that the necessary construction information always is available in the BIM kiosk's model. Examples of information missing from the exported data: the installation height of sockets and the diameter of pipes.

Photo: Statsbygg
Hans Thomas Holm

A «room diamond» was gradually set up in the model as well. The room diamond is a geometry object that is placed in the rooms and contains special information, such as room diagrams or specified details. Clicking on the room diamond brings up a hyperlink to the relevant information in the web hotel. The KHiB project also created direct links from the IFC model's various control area objects to specially organised drawing packages prepared by the architect for the individual area.

As a result of the success of BIM kiosks on several other Statsbygg building sites and at KHiB, the kiosks are now also commercially available.



BIM roles in the project

The project had dedicated BIM resources throughout design and construction. In the design phase, the BIM coordinators for both the architect and all the technical disciplines handled model collation, model coordination, the BIM implementation plan, quality assurance, and all computer-related clarifications and challenges to do with BIM.

During the construction phase, the client had a dedicated BIM site manager working approximately half time. The site manager's role includes getting BIM to work optimally on the construction site. This means assisting with training and model use, dataflow, adaptation of BIM kiosks, setting up case handling tools, monitoring BIM kiosks for users, running the cross-disciplinary model review process, and organising the model for the construction site.

Each contract also required BIM resources to be provided to handle model use and checks within the contract in question. During the construction phase, the BIM resources from the design group were available, too, in particular the BIM managers for each design discipline.

With rapidly increasing digitalisation in the construction industry, the use of dedicated BIM resources is an as yet underestimated necessity. Such resources are strongly recommended at every stage and level; for design personnel, for contractors, for key suppliers, for site managers, for future operating departments, and for the client.



Describing the use of BIM

All the construction contracts in the KHiB project had a separate section of cost items relating to digital interaction. These items were intended to ensure a level playing field for quotation and execution, including the use of BIM.

They should describe requirements for the following:

- Tablet use and training in digital case handling.
- Setting up a construction site network with speed requirements and coverage specification.
- Setting up the required number of BIM kiosks plus specifications for equipment, updates, and software.
- Training in the use of BIM kiosks and software for model transparency, clash detections and buildability checks, quantity take-off, and model-based communication.
- BIM supplier design.
- Checks on the IFC model supplied and verification of buildability.
- Design of 3D reinforcement to avoid traditional 2D bar schedules (which more often than not have expired).
- Laser scanning of completed shell.
- Use of the project's web hotel.
- Information on drawings only being supplied digitally and printouts having to be taken care of by the contractor where needed.
- Requirements for As-built documentation.
- Use of the dRofus and TIDA platforms (room and equipment databases). (This requirement is specific to projects managed by Statsbygg.)

Photo: Statsbygg
Hans Thomas Holm



BIM-kiosk

What

A BIM-kiosk is a standalone PC with a large screen. Here the whole building is visualised in a single three dimensional (3D) model. One can quickly see how a finished room and the finished building should look. One can easily read and understand measurements, distances, dimensions, and other variables.

Why

There are now digital tools which provide excellent visualisation of the building and its details in a 3D model. A vast amount of information is gathered and shared into one easily accessible place. The data should always be updated. The amount of paper, the number of revisions, and the sources of errors will be minimised. It makes it easier for the workers to understand amongst others spaces, lengths, distances, and depths. Further, the follow-up of quality of their own and others work can be improved. The BIM-kiosks should be easily accessible on the construction site.

Where

There should be at least one BIM-kiosk on each floor. These are not static, but can be moved to wherever they are needed (on wheels). The KHiB-project consisted of six BIM-kiosks.

Training

The project offered free training in the use and understanding of the 3D-model in the BIM-kiosk. All workers were recommended to complete this training. The BIM Site manager (a separate role) could be contacted when needed for further training. The BIM Site manager was also available in the building to provide assistance in use and understanding of the BIM-kiosk.

Photo: Statsbygg
Trond Isaksen



The model vs drawings and use

The IFC model was used a lot by administrative staff, the contractors, and the suppliers alike. Experience shows that the model is of great benefit to technical disciplines, and they use it diligently. The construction disciplines benefit most from the cross-disciplinary coordination in the model, which is carried out ahead of execution. Model use provides:

- good visualisation and cross-disciplinary understanding,
- the option of supplementary information for drawings, e.g. for measurement, 3D information that does not appear on a drawing, and information on properties,
- a discussion basis for meetings and the construction site,
- quantity take-off,
- advantageous adaptations to the KHiB projects' «takt and parade of trades»,
- clash detections, and
- checks on buildability.

The project established the principle of «the model taking precedence over and being better than the drawing». There were several discussions about whether changes should be updated both on the drawing and in the model. Although the model takes precedence over the drawing, experience shows that the tradespeople often use drawings. The model and drawing therefore have to tally. Drawings also contain information that does not always appear in the model. All details are prepared in 2D, for example.

Where the model does not manage to describe elements, tasks, requirements, and the like adequately, technical disciplines supplied an «exception list». This list describes what does not appear in the model, for which the drawing or other documentation must be consulted. The exception list and ARCH details are the only areas where the drawing takes precedence over the model.

An example of an issue where the model was of help: Doorway studs that cannot go up to the ceiling because the ventilation ducts above the door cut through them. As a result, the walls are not rigid enough. In order to discover and catch this issue, a control rule was set up in Solibri to identify where this issue occurs (geometrically). Similar examples include incorrect placement of fire detectors and necessary clearance between technical equipment and ceilings.

Measurement errors in the model

If the construction site is to be able to use the model as a good substitute for the drawings, it is important to find good methods for taking measurements from the model. There is rapid development of digital tools that improve functionality and accuracy for measurements with handheld devices, but in the KHiB project this type of measurement largely took place at the BIM kiosk.

The project made the model available on tablets, but experience shows that navigation and annotation do not work well enough yet. There were some errors on the construction site relating to measurements in the model. These were generally due to the measurement not being related to the axis grid.

BIM training

In the KHiB project, training in the use of BIM kiosks and the case handling tools took the form of short sessions with a small number of participants. Experience shows that supplementary follow-up and training of tradespeople directly on the construction site are both necessary and effective. This is best done by walking around and helping people out with useful solutions and advice when they are at the BIM kiosk. There is frequently more than one person at the BIM kiosks at the same time, so it is generally possible to pass on useful information to several people. The tradespeople often discuss things among themselves, so information spreads quickly and informally. This also makes it easier for the tradespeople to ask questions, which they may find uncomfortable in more formal training sessions.

Gradually, as more and more tradespeople at the various construction sites become familiar with Solibri Model Viewer or similar software, the need for training will decline accordingly. There will nevertheless always be a need for project-specific training and follow-up.

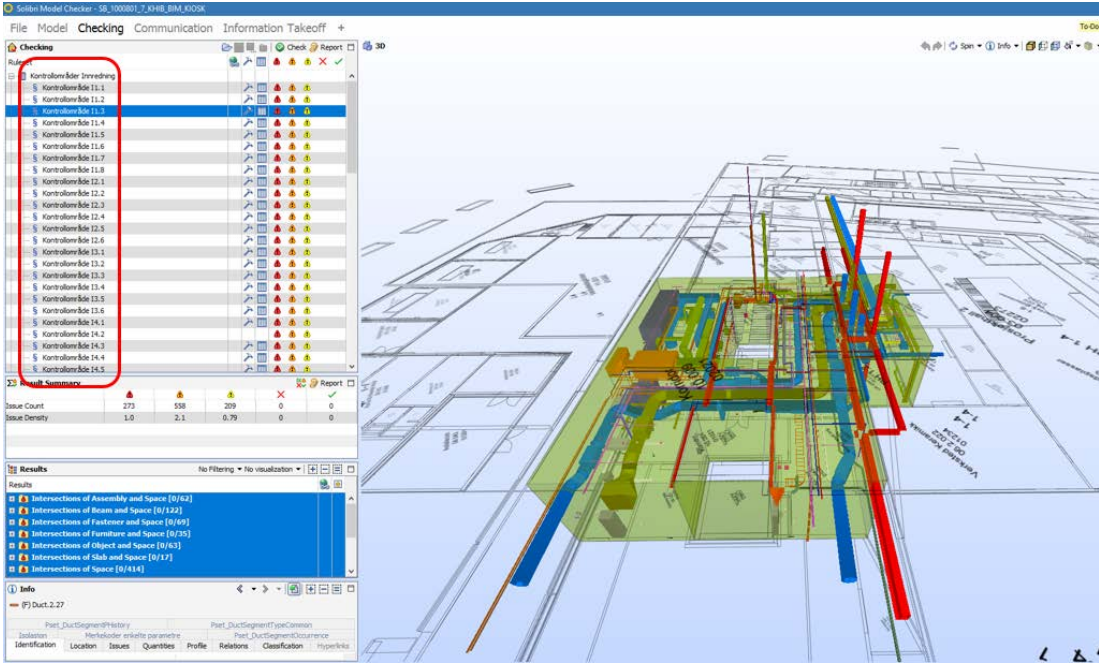


BIM work processes

The contractors' BIM manager and administrative personnel benefit greatly from familiarising themselves with the model at an early stage. It provides valuable information on what is to be built and how everything is connected with other contracts. The model is an important planning tool for arriving successfully at the final result. Quantity control and ordering can be done straight from the model to an ever-increasing extent. In the KHiB project, the contractors were also required to go through the model to assess buildability and complexity.

The building is divided into control areas. (See the chapter Lean Construction for further information.) The project conducted cross-disciplinary model reviews for each control area at least four weeks before start-up in the area in question. This identified challenges with regard to buildability, clashes, and progress. The meetings are attended by the contractors represented by their foremen and BIM managers, the design group represented by the discipline managers, and the client represented by the site managers. BCF reports (see previous section) are generated containing screen shots and comments about what the issue is and who is responsible for closing it.

Experience shows that it is important for the site managers to use the BIM model actively in meetings and as a basis.



Digital management of issues

The project used the BIM 360 Field solution (from Autodesk) to deal with most of the issues relating to nonconformity handling. This solution has a drawing library that reflects the project's web hotel (ITbase) and allows the 3D model to be displayed with limited functionality. BIM 360 Field is also used for checklists from safety inspections and completion checks. The project adapted BIM 360 Field to its own needs, but this can also be generated from the supplier. One needs to be aware of the needs and how they best can be used.

The system for the KHiB project was set up in such a way that each site manager had separate lists with issues for follow-up. The case flow is defined in such a way that all issues between the design group and the contractors go through the site management. The status of open issues was a fixed item on the agenda at the weekly site manager meeting. The system handled around 6,000 cases that would otherwise have been recorded in a countless and complex number of lists and Excel spreadsheets.

There are several competing systems to BIM 360 Field. One needs to assess their advantages and disadvantages based on the specific project's needs. Experience from the KHiB project shows that one needs to have an easy-to-understand interface for the people who are to use the software (it must be simple and logical in its structure, readability, and use), and that all the project participants must commit to the chosen system and make full use of it. Nor should one be afraid to scrap a chosen system if it turns out to be counterproductive. (This can be a hard decision to make, however.)

Illustration:
Cross-disciplinary check
of control areas

BIM adapted control areas

The BIM model(s) in the KHiB project was/were adapted to Lean control areas. The division of control areas in the model was carried out by creating Space objects in the design tool, which were then used in the transparency and viewer tool Solibri. In the construction, the various control areas were clearly marked with colours on the floor. In this way, we illustrated the link between the model and the actual construction process.

In our experience, the model worked well when it came to prepare the interaction and logistics between the different activities as they gradually entered the control areas. The BIM model was used actively to discuss installation order. Issues that would otherwise have cropped up during installation on site, were frequently solved and adjusted ahead of installation. Sometimes this also led to the order of activities being adjusted. The conversations concerning the model were also a good arena for interactions: the tradespeople and the managers got to know each other well and could take joint responsibility for construction being carried out optimally for as many participants as possible.



Facts and Postscript



Glossary on KHiB

LEAN principles on KHiB

- Creating maximum workflow.
- Teamwork and coordinated movement from one area to another in the building.
- Continuously learning from our mistakes and constantly improving. (The zero-error principle).
- Reducing waste and unnecessary work.
- Seeing and understanding the bigger picture.

The bigger picture

In order to succeed in your task, it is important to see the bigger picture. The timetable, transparency, and openness are factors that should contribute to the bigger picture. It is important that you are able to work with your own details, but also be able to see the whole project.

Flow

The flow in the KHiB project means a smooth and stable execution of tasks and activities based on the timetable. This means that the resources must be adaptable to the tasks.

Reverse planning

Based on the deadline of a task or work operation. For example, in an inspection area, you count a certain number of weeks backwards to find out when you need to start working on the task. This makes it easier to see whether you have the time to complete the task.

Process

Process describes the sequence of activities following each other in the correct order. In the KHiB project, we call it a “train”.

Transparency

For the KHiB project, transparency means that everyone can observe and understand each other. Observing what others are doing, and letting others observe what you are doing, will contribute to making each other better. For example, plans, overviews, and suggestions should be made big, visible, and easy to understand. We all have the same objectives, and we are all working in the same building, so everyone needs to be able to see the same.

Openness

Openness means that everyone should be able to speak up about anything, whether it is positive or something that needs improving. Provide good and/or constructive feedback upwards, sideways, and downwards through the hierarchy. Openness makes everyone better – all the time.

SHE/HSE/SJA

Safety – Health – Environment / Health – Safety – Environment. Must provide the foundation of all work. It is expected that everyone uses the appropriate protective equipment, conducts a Safe Job Analysis (SJA) (Risk Assessment), and clears the construction site every day for a Clean Dry Building (CDB).

SJA

SJA = Safe Job Analysis. SJA is in short a risk assessment. One should analyse difficult, complex, and cross functional work operations, with emphasis on being safe, before execution.

CDB

CDB = Clean Dry Building. CDB is the processes and protocols that continuously ensure that the building is tidy and free of dust throughout the whole construction phase. Proactively, the tidiness of the construction site promotes good health amongst the workers. It also influences the tone amongst the workers and the quality of all technical equipment that will be installed. A clean building in turn positively influences all those later moving in.

RUH (RUI)

RUH = «Rapport Uønsket Hendelse» = Report Unwanted Incident (RUI). RUH is a system registering different types of incidents on the construction site. This system is then used for learning and to improve future work, thereby avoiding repetitive mistakes.

**Systematic Completion**

The project has been working systematically and thoroughly to prepare an implementation plan for how the building should be continuously tested and inspected during construction and when the construction work is completed. The goal is to create a building that works as intended and is as error-free as possible, so that no one needs to come back time and time again, to «fix things». All these activities have been compiled under a separate process called Systematic Completion.

Proactive

Proactive means to come prepared, to be forward thinking, and to contribute to avoid obstacles and errors that traditionally occur. This means that a worker can constantly have a positive impact on his own working day, as well as his co-worker's working day. The tasks are only done once, and they are executed correctly. The KHiB-project works to be proactive at all levels.

Facts

Contractual partners

Client	Ministry of Education and Research
Owner	Statsbygg
Project and Design Management	Atkins Norge
Site Management	Fylkesnes AS
Design group	Architecture and landscape: Snøhetta Oslo AS
	Engineers: Rambøll AS
	Porsche Consulting
Lean Consultants	

Contractors

AF Decom	K201 (Demolition/excavation)
FAS	K202 (Piling)
Bolseth Glass	K204 (Facade)
Veidekke Entreprenør	K205/K206 (Structure/Interior works)
Apply TB	K401/K301/K302 (Electro/HVAC)
Schneider Electric Norge	K501 (Automization/SD)
ThyssenKrupp Elevator	K601 (Elevator)
Svein Boasson	K701 (Outdoor works)

Key Facts

Project start and design competition	Spring 2005
Funding	June 2013
Total cost (as of July 2013)	1,038 MNOK (incl. VAT)
Energy level	Passivhaus
Gross area (as of April 2015)	14,800 sqm
Contract form	Design Bid Build (11 contracts)

Progress plan

2014	Demolition / Excavation / Sheet piling
2015	Groundwork-Piling / Cast in situ / Shell
2016–2017	Façade Interior finishing work / Outdoor work
2017	Testing / Completion
2017	Ready for 9 months of trial operation
	Semester start
	Official opening
2018	Final takeover
	28th April
	17th August
	11th October
	28th January

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Snøhetta and SNOflow

In 2013, the Snøhetta design team embarked on an ambitious journey together with our partners in the KHiB-project. By seeing a potential to challenge existing industry standards we developed new key principles in Lean in the complex merge of design, construction and BIM technology.

At that time Lean had already proven successful results in the production and construction industry. The key questions we asked our self were;

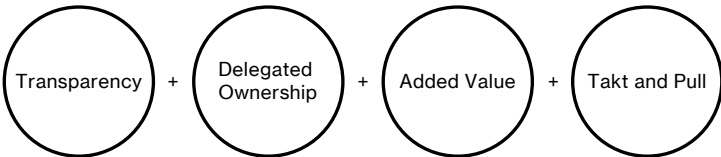
- Can it be possible to transfer Lean philosophy into exchange of information in the design phase?
- Can knowledge-based information flows be broken down into manageable packages allowing the designers to in alignment move forward in the same rhythm?
- Basically speaking, can design be looked upon as a production line, as a continuous flow of information.

We chose the BIM-model to be our product, seamlessly merging from the virtual to the physical, today known as a «Digital Twin».

Learnings from long term agile leadership and practice in the fields of architecture, brand- and product-design was exchanged with extremely skilled professionals in the KHiB-team. Together we developed a mindset that has shown to be a game changer in the Norwegian building industry.

SNOflow – combining Snøhettas work methodology with Lean

SNOflow is today Snøhetta's project management model, a value-based and Lean-anchored method based on Snøhetta's 30 years' experience of how we work together to deliver successful projects. SNOflow combines our processual thinking and work-together approach with acknowledged Lean strategies and philosophy and is based on a set of core values: **transparency, delegated ownership, added value** and the Lean principles of **takt & pull**.



Snøhetta's work methodology is placing experience at the center of our design processes we value and foster social and professional interaction. This means Snøhetta's processes are rooted in a wide range of tools, professional skills and theoretical backgrounds, and a good portion of generosity and respect. We call this interdisciplinary interaction "transpositioning". Through our years of experience, Snøhetta has developed strategies to enhance communication and optimize processes in a complex industry with a myriad of experts. This "tacit knowledge" is reflected in SNOflow and helps us stay true to our common values and processes. At Snøhetta, SNOflow reaches into the entire spectrum of our services, from architecture, interior architecture and landscape architecture to graphic and product design.

SNOflow is meant to be a mindset of dynamic tools allowing Snøhetta's project leaders to successfully steer global teams through all types of projects, even the most complex. Our methods are based on the idea that each client, project and process is unique. Each process needs tailored tools to attain agreed-upon goals.

How SNOflow works

The SNOflow-tools are carefully selected and distributed to give guidance in the different phases and processes needed to make a project come into reality, from the very first idea – to function. It is our mission to create buildings, designs and products that add value, our deliverables become meaningful first when taken into use and shown to fulfill the mission given.

SNOflow tools are distributed along two axes:

- Horizontally: Project matureness – time
- Vertically: Project processes

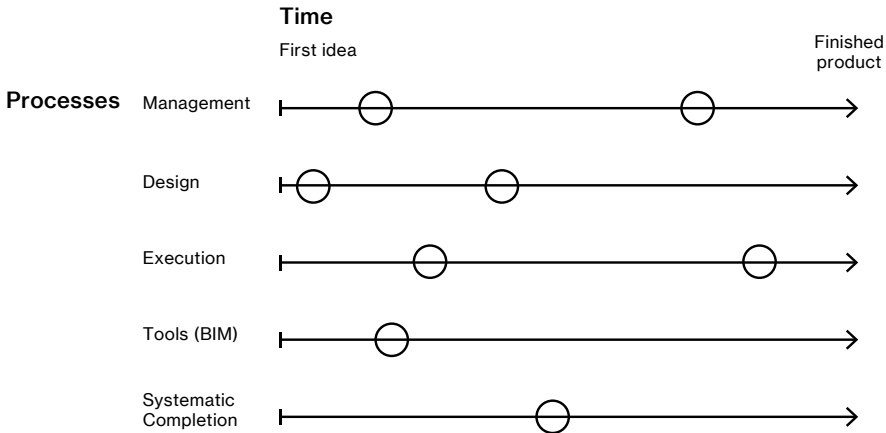


Illustration: Snøhetta

Central to all Snøhetta project are the two tools of Hand-over completed and Project evaluation completed, serving as a basis for all project startups and finalization phases. First tool ensures quality and common goal setting between Snøhetta management and projects, last tools ensures continuous improvement and sharing of learnings. The selection of tools to be used between the two phases is tailored to each project, depending on phase and complexity. The tools consist of Snøhetta-developed methods, project leadership advices and team-guidance's, quality management tools and Lean methods. Central to selection is our quality management system and ISO-certification, sourced and managed through the selection process. Use of Lean tools are managed individually for each project. The complexity of information in large-scale projects is one of the most significant challenges design and construction management faces today. Though our tools are more powerful and more sophisticated than ever, we need to establish new methods for optimizing information flow. This is best achieved through a holistic approach in Process- and Design Management which again is manifesting the importance of Lean thinking and BIM working together to avoid fatal mistakes which costs both clients and society millions each year.



Postscript Statsbygg

The excellent experiences from the project The Academy of Art and Design in Bergen will be used again and again, and improved even further. Because some booklets were written at an early stage, the team continued to learn from and develop different topics throughout the project. New knowledge has also been developed and added since then. By everyone in their own way.

At the finalization of this compilation, by March 2019, the team has naturally (and unfortunately) been spread in different directions.

Site Management feedback

The site managers from Fylkesnes, who at the start of the KHiB project had their main attention on finishing the construction as correctly as possible, have changed their primary focus. They now know that the magic key to success is an early and organized plan based on the systematic completion, ie. function. Several projects under their management in Bergen have since been on schedule, on budget, with close to zero errors, and no correctional works at handover date – a date agreed in advance. In addition, all stakeholders have left the project with a good and proud feeling of a perfect collaboration.

Facility Management feedback

Statsbygg Facility Management has considered it a privilege to follow the KHiB project. The project has been handled in an outstanding way. The factors of success, in short, are a combination of integrated and systematic collaboration throughout the phases and gateways of the project, a formal handover of the building to operations and facility management, and a trial and guarantee period well planned and carried through.

The main part of success is due to a well-documented process for systematic completion, which includes testing of the construction and all the technical systems.

The process for a successful completion and handover of the construction is in short:

- Main Process: Systematic Completion
- Sub Processes: Tests / Training / MOM documentation / Service Agreements
- Foundations: Systems List / Functional Specifications (system by system and integrated, including acceptance criteria) / System Diagrams / Test Procedures

Handing over the completed construction without errors to facility management, even prior to the customer and user moving in, has added a lot of value to Statsbygg as an owner. All the technical systems, including advanced user equipment, had been cross-functionally tested in collaboration with operations throughout the detailed design and construction processes.

The project management and the facility management collaborated through all kinds of meetings. During the trial period a separate board of leaders, meeting at regular intervals, ensured that operations fully understood their responsibility of facility management and the project was able to hand over and conclude the delivery in a structured fashion. Being present from day one, facility management and operations were able to learn and understand the complexity of the building about to be delivered, which also added value to the subsequent operations. Management, operations, and maintenance (MOM) of the construction after handover went smoothly due to the successive elimination of errors along the construction phase and before the trial period started. One key factor to success was the mutual and committing collaboration and clearly divided responsibilities between the staff of project and operations.

The Lean philosophy of the project has been used consequently from day one. The project methodology combining Lean, systematic completion, and integrated collaboration with support from high level management within the company, has given great results. The KHiB project has also been used as a pilot for an improved quality of the Statsbygg project model. All in all, the project has added value to Statsbygg through learning and collaboration, saving costs through high quality, correct functionality, fully tested technical systems, and handover on cost and time.

«Facility Management considers this project a huge success. We have received a building free of errors, a wide specter of new knowledge, and an efficient structure – in the perspective of Life Cycle Cost (LCC) as well. Thank you very much for a great project and a fantastic collaboration!»

What is next for the Project Management

Some members of the management team from Statsbygg and Atkins have since January 2018 continued to work together on the project Life Science for the University of Oslo. It is a highly advanced research and education facility to be completed by December 2024. Project numbers are approximately 70,000 sqm at a construction cost budget of 5,700 mill. NOK and a user equipment cost budget of 1,140 mill. NOK. (July 2018-numbers.) Our vision for this project is «An even better project». With one team and one culture.

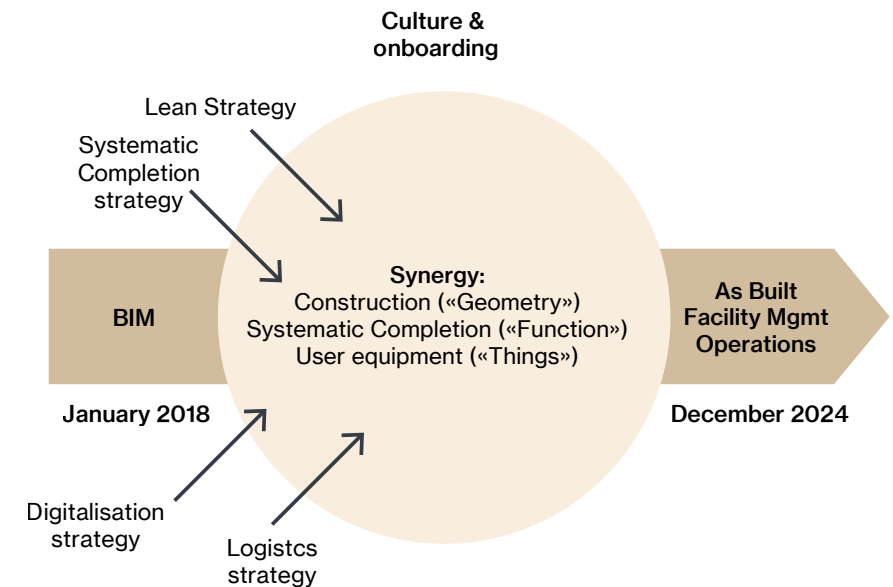
Below find some illustrations from the project. They are meant to serve as an inspiration for anyone who has interest in making contact to learn even more. Another intention is to visualize how we think in the project Life Science.

The first illustration shows how the project is based around five central strategies:

- 1) The Contract Strategy: Collaboration first.
Completed design. Seven parallel build contracts.
- 2) The Lean Strategy
- 3) The Systematic Completion Strategy
- 4) The Digitalization Strategy
- 5) The Logistics Strategy

All five strategies belong together since «Everything is connected», and we combine construction, user equipment, and systematic completion from day one. BIM is the design tool throughout the whole project.

Holistic view of Strategies in Project Life Science

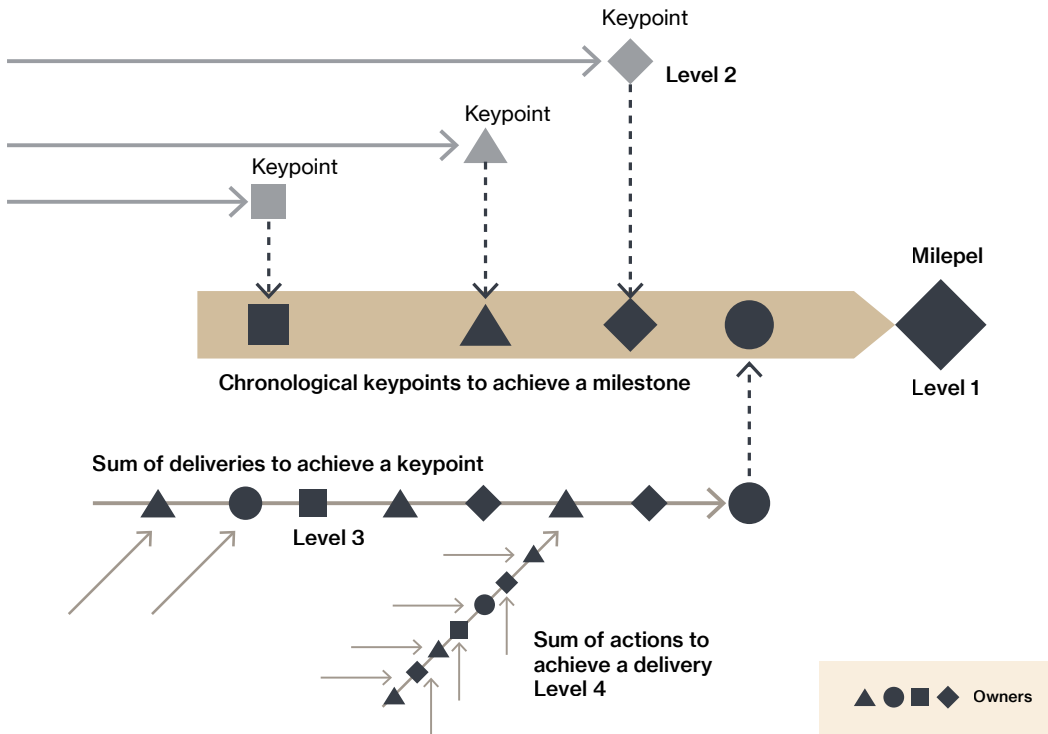


Contract Strategy: Collaboration. Design completed.
7 parallel Bid-Builds. Involving contractors and suppliers very early.
Taktplanning. «7 conditions for a sound activity»

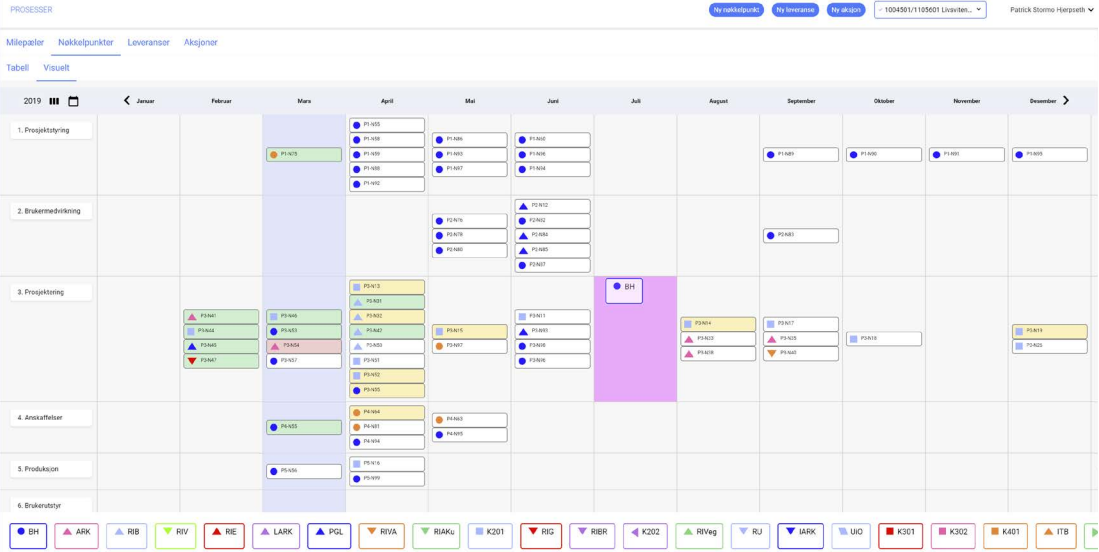
Further, the project is developing a way of working that puts the now standardised design processes into an organised, transparent, and cross-functional system. «Cogito Project» has been chosen as the preferred process visualisation planning tool (CogitoProject.com). The tool visualises the main processes of the project, and it visualises on four different levels the milestones, the key points, the deliveries, and the actions. The combination of processes and the four different levels is illustrated in a separate print screen. The post-it cards from the four different levels can easily be created and moved around by a drag-and-drop-method. Cleverly designed dashboards also visualise PPC's, ie. Planned Percent Completed, and causes for delays and due-date changes.

The next illustrations illustrates how milestones, keypoints, deliveries, and actions are generically combined, and how they can be visualised in the tool.

Lean Process Planning in Life Science
Combining Milestones-Keypoints-Deliveries-Actions



Despite the extreme complexity of the new project, we sincerely aim at completing another successful project by the end of 2024.



- Translations**
- Milepæler: Milestones
 - Nøkkelpunkter: Key points
 - Leveranser: Deliveries
 - Aksjoner: Actions
 - Prosjektstyring: Project management
 - Brukermedvirkning: User involvement
 - Prosjektering: Design
 - Anskaffelser: Procurement
 - Produksjon: Construction
 - Brukerutstyr: User equipment

Illustration previous page:
Generically combining milestones, keypoints, deliveries, and actions.

Illustration this page:
A print screen from «Cogito Project».









Links to Atkins' videos about the project:

<https://youtu.be/dRR6xeuQdaM>

<https://youtu.be/GyL11KJDB2k>

The booklets were finalized on the following dates:

Lean Strategy	December 4th 2017
Lean Design	November 9th 2018
Systematic Completion	September 25th 2017
Lean Construction (version 2)	November 14th 2017
BIM@KHiB	September 19th 2018

Throughout both the design and construction stages, the objective of the KHiB project was to work extensively with Lean principles, Lean mentality, and Lean methods. The project developed its own methodology to be able to work more smartly and correctly with the extensive planning work. It was named Lean Process Planning (also known as Milestone Planning) and Lean Design. This mindset may in many respects be considered as pioneering work.

The KHiB project further developed the highly important process Systematic Completion, which is a structured continuous test procedure of all the systems and functions. This work has to be initialised much earlier than traditionally normal, and it is in the end expected to lead to a successful and error free delivery of the construction.

The KHiB project wrote a total of five booklets. They describe the following topics: Lean Strategy, Lean Design, Systematic Completion, Lean Construction, and BIM@KHiB. In this book all five booklets have been compiled. The intention of this book is to give a good overview over what has been done in the project and how. Subsequently we hope to contribute to an improving industry.

The KHiB Team

