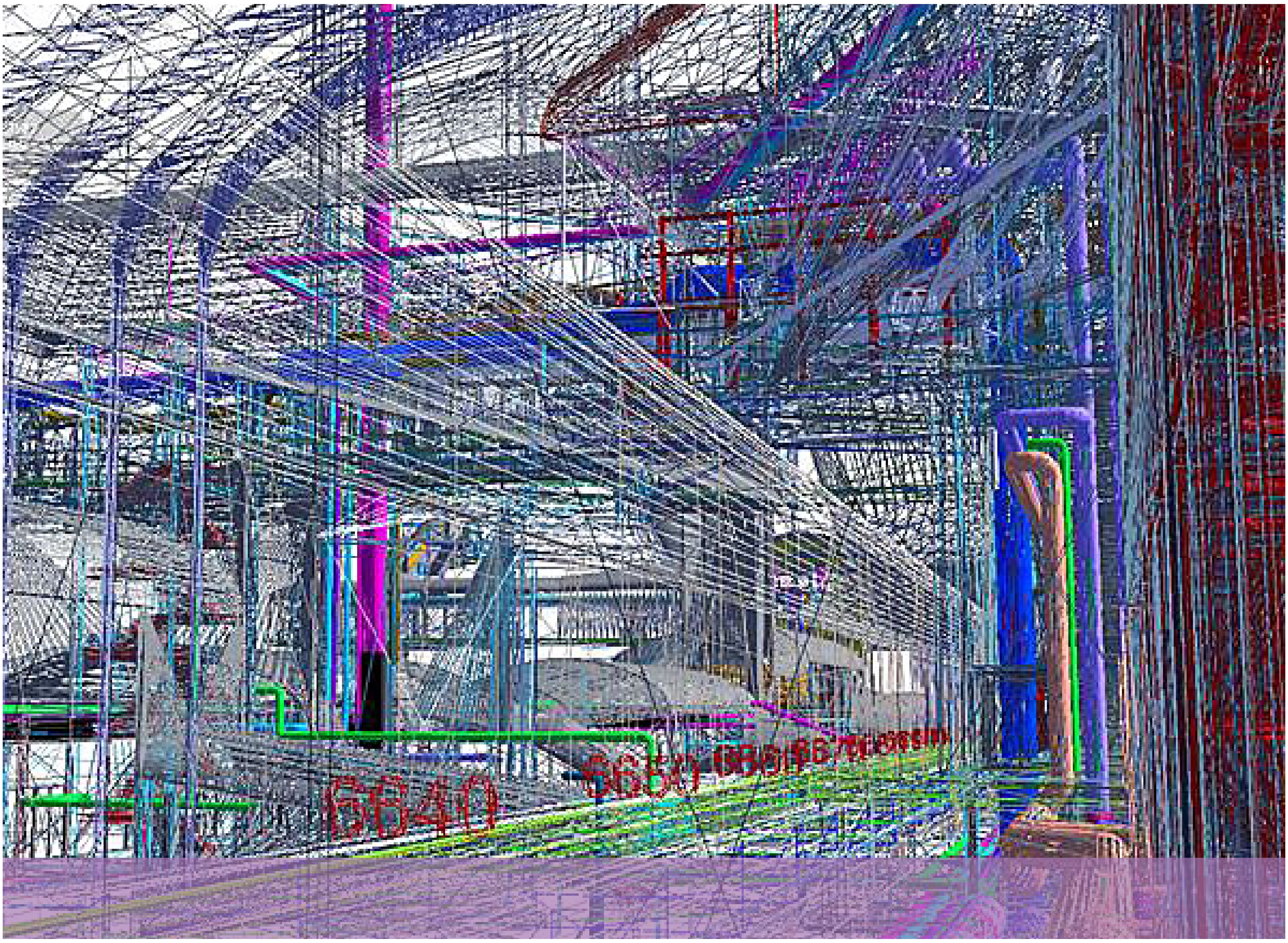
Thesis

4/2016

Pietari Pellinen

Developing design process management in BIM based project involving infrastructure and construction engineering



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Keywords: BIM, Design Management, Collaboration, Co-operation, Process

Summary

BIM has been acknowledged as a beneficial tool for the design work in construction projects. The use of the tool has caused changes in co-operation practices and they are still developing. The meaning of the thesis was to find out the current processes of BIM collaboration and to further develop them from the perspective of design management.

The use of BIM in large-scale projects, involving infrastructure engineering and construction engineering, is a subject that has not been researched to any great extent. This is why the thesis focuses on that framework.

The theory of the thesis consists of BIM guidelines and project management features of lean construction, concurrent engineering, project alliancing, integrated project delivery and knotworking.

Empirical data was gathered from a case project, the City Rail Loop in Helsinki. Empirical data includes interviews, project meeting analytics and common data area analytics.

In combination of theory and empirical data, new processes for collaboration between design disciplines were developed in the thesis. In addition to new processes, a list of suggestions for BIM based design projects was developed.

Pietari Pellinen: Suunnitteluprosessin hallinnan kehittäminen BIM pohjaisessa hankkeessa, joka sisältää infra- ja talonrakennusta. Opinnäytetyö 4/2016. Liikennevirasto, hankehallintaosasto. Helsinki 2016. 100 sivua ja 4 liitettä. ISSN 2343-1741, ISBN 978-952-317-227-2.

Avainsanat: BIM, suunnittelun hallinta, yhteistyö, yhteistoiminta, prosessi

Tiivistelmä

BIM on tiedostettu hyödylliseksi työkaluksi käytettäväksi rakennusprojektien suunnittelussa. Työkalun käyttäminen on aiheuttanut muutoksia yhteistyökäytännöissä ja ne kehittyvät edelleen. Tämän diplomityön tarkoitus oli tutkia nykyisiä käytäntöjä ja miten niitä voitaisiin edelleen kehittää.

BIMin käyttöä suurissa rakennusprojekteissa, joissa on infrastruktuurisuunnittelua ja talonrakennussuunnittelua, ei aikaisemmin ollut tutkittu paljon. Tämän takia diplomityö keskittyy tähän viitekehykseen.

Diplomityön teoriaosuus koostuu BIM-ohjeista ja projektin hallinnan näkökulmasta käsiteltynä teorioista: lean construction, concurrent engineering, projekti allianssi, integrated project delivery ja solmutyöskentely.

Empiirinen data diplomityöhön on kerätty Pisararata hankkeesta. Empiiriseen dataan sisältyy haastatteluja, projekti palaverien analysointi ja projektipankki datan analysointi.

Teoriaosuuden ja empiirisen datan yhdistelmänä diplomityössä on kehitetty uusi prosessi suunnittelualojen väliseen yhteistyöhön rakennusprojektissa. Uuden prosessin lisäksi diplomityössä on myös muodostettu listaus ohjeista BIM-pohjaisille suunnitteluhankkeille.

Pietari Pellinen: Utvecklande av processledning i BIM-baserade projekt som innehåller infrastruktur- och byggnadsplanering. Trafikverket, projekthantering. Helsingfors 2016. Lärdomsprov 4/2016. 100 sidor och 4 bilagor. ISSN 2343-1741, ISBN 978-952-317-227-2.

Sammandrag

BIM har konstaterats vara ett nyttigt verktyg när byggprojekt planeras. Verktyget har medfört förändringar i samarbetspraxisen, som utvecklas kontinuerligt. Avsikten med detta diplomarbete är att undersöka den nuvarande praxisen och hur denna kunde utvecklas ytterligare.

Det finns inte mycket tidigare forskning om användningen av BIM i stora byggprojekt som innehåller infrastruktur- och husbyggnadsplanering. Därför har den referens-ramen använts i detta diplomarbete.

Teoridelen i diplomarbetet består av BIM-instruktioner och teorier som behandlats ur projektledningssynvinkel: lean construction, concurrent engineering, projektallians, integrated project delivery och knotworking.

Empiriska data för diplomarbetet har samlats in från Centrumslingan-projektet och dessa omfattar intervjuer, analyser av projektmöten samt av data i projektbanken.

I diplomarbetet har man kombinerat teoridelen och empiriska data för att utveckla en ny process för samarbete mellan planeringsbranscherna i olika byggprojekt. Utöver den nya processen innehåller diplomarbetet också en lista över instruktioner som kan användas i BIM-baserade planeringsprojekt.

Preface

Establishing BIM as a design tool causes changes in project processes and in co-operation between designers. BIM has become the standard tool for large projects. The processes and co-operation methods are not fully efficient and there is room for improvement.

This thesis has been made to map current used design processes and co-operation. The goal of the thesis was to further develop co-operation processes between designers in a project. This thesis is made by Pietari Pellinen from Aalto University. Research was done by following project meetings and interviewing personnel in City Rail Loop project. Results of the empirical data were combined with the findings from literature study to produce new more efficient co-operation processes. In addition to these processes, a list of suggestions was developed for BIM project participants.

Procurer for this thesis was the head of information modeling development Tiina Perttula from Finnish Transport Agency. Other members of the thesis steering group were Perttu Valtonen from Sweco PM, Tarja Mäkeläinen from VTT and Vishal Singh from Aalto University.

Helsinki, March 2016

Finnish Transport Agency
Project Management

Content

APPENDICES

Common data area analytics tables and examples of original data

Abbreviations

AEC industry	Architecture, Engineering and Construction industry
BEP	BIM Execution Plan
BIM	Building information model
CE	Concurrent Engineering
CRL	City Rail Loop
DSM	Design Structure Matrix
FTA	Finnish Transport Agency
HPAC	Heating, plumbing and air-conditioning
IPD	Integrated Project Delivery
Lean	Production development philosophy
Lean construction	Application of Lean to construction industry
LOD	Level of Development
LOI	Level of Information
LPS	Last Planner System
Mass-model	Rough architecture model with the placement of building masses
PA	Project Alliance
TOC	Target Outrun Cost
TPS	Toyota Production System – The base of Lean
VDC	Virtual Design and Construction
VSM	Value Stream Mapping

Common data area = Project data bank

1 Introduction

1.1 Backround

Modern construction projects are often challenged by delays and other time-related uncertainties. Delays are often caused by poor communication, ambiguous requirements, and regular misunderstandings in the industry (Forbes and Ahmed 2011, Cremona 2011). Collaboration problems are commonly identified as one of the main factors affecting the low productivity and ineffectiveness in construction industry. Due to an increasing complexity of the projects, establishing more integrated approaches is required in construction design (Codinhoto and Formoso 2005).

Applying building information modeling to a design process is a growing trend in the field of construction. The advantages of BIM have been noticed especially in large multimillion design projects. In these large design projects, especially involving many different design fields that use different software, the use of BIM and the changes it will make to the design processes is an area that has not been researched much before. These new processes are now developing as BIM is for the first time implemented in this large scale to a project that has such many different design fields.

Learning new design processes from the project City Rail Loop, ordered by Finnish Transport Agency and city of Helsinki, was a fruitful opportunity. City Rail Loop is a project where these new BIM practices were for the first time demanded at this kind of project at this large scale. It was realized that developing these new practices will demand resources and decision were made to prepare for this. This fruitful opportunity was the reason to select City Rail Loop as the case project for this thesis. Inside the project there were also three separate design groups that were individually solving these new problems. Following these groups was hoped to give comparable solutions to problems of BIM based design.

The Finnish transport agency had realized the advantages of BIM in the information transfer aspect and in the aspect of achieving better design. Decisions were made to demand BIM based design and development of process from the designers.

This Master's Thesis started from the need to document these new developed practices in the case project as well as to develop them further. The master's thesis was made to take these developed practices to next projects that will also be produced in BIM based design.

1.2 Case Project: City Rail Loop

Case project was selected under research for several reasons. One of the reasons is that BIM is implemented in to a real project for the first time at this scale in Finland to both building and infrastructure engineering simultaneously. This was hoped to give insight on how to solve new challenges and take advantage of opportunities that implementation would develop. Third reason for selecting this case project is that there were three separate design groups involved in the project. Their approach to problem solving and to BIM processes were known to be slightly different. Comparison of these different approaches was wished to give good results in improving design management processes.

City Rail Loop is a planned urban railway line for commuter trains under the Helsinki city center. The loop-shaped railway starts in Pasila and runs in a tunnel via Töölö, Helsinki city center, Hakaniemi and back to Pasila.

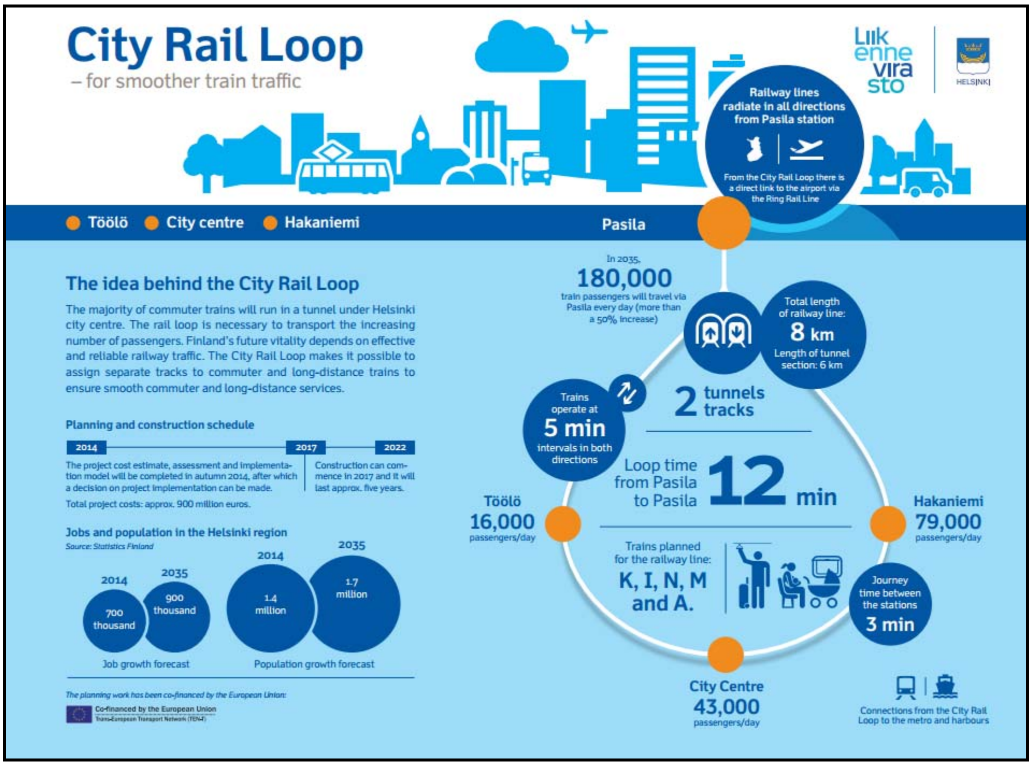
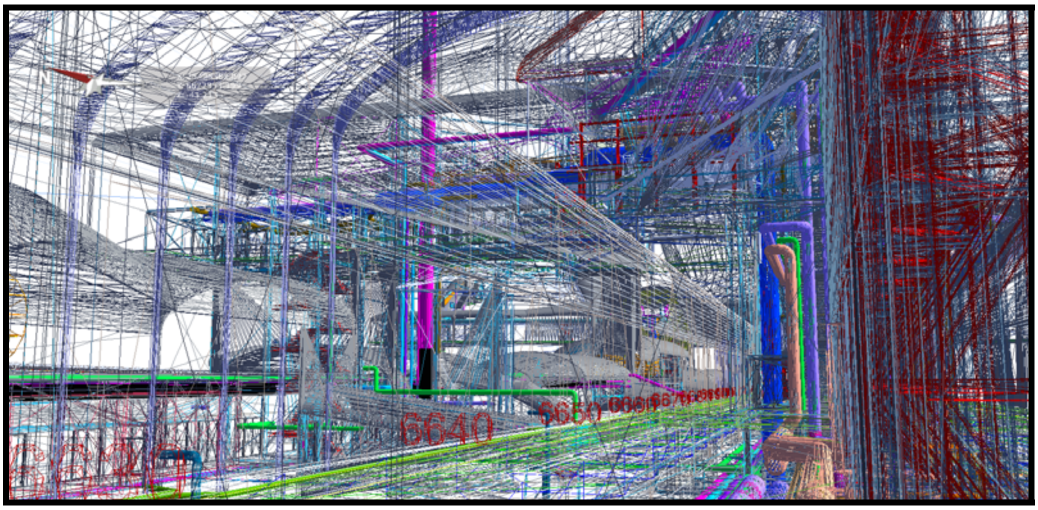


Figure 1 *City Rail Loop Infographic*

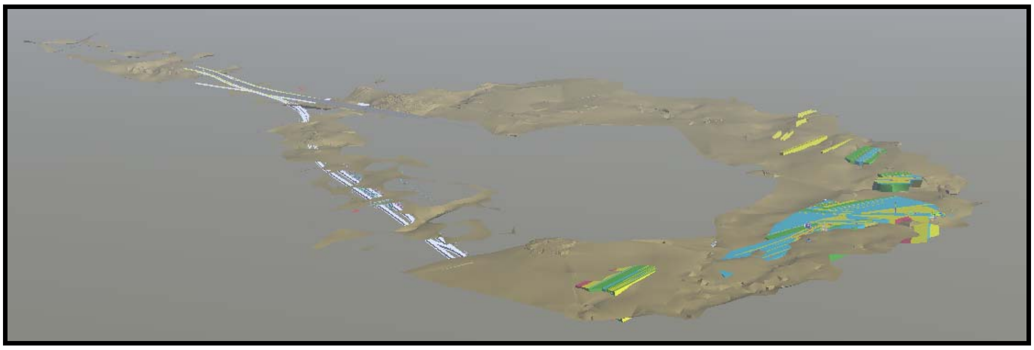
The public transport system must be able to accommodate a continuously growing number of passengers. At present there are nearly 1.4 million inhabitants in the Helsinki region. This number is expected to increase by 40,000 this decade and by more than 400,000 during the next few decades.



Picture 1 Screenshot of the City Rail Loop model (Finnish Transport Agency 2015)

The City Rail Loop will enable efficient railway traffic in a large area. As a result of the new railway section, rail capacity can be freed up on the now too congested stretch between Helsinki and Pasila, allowing trains to run at more frequent intervals.

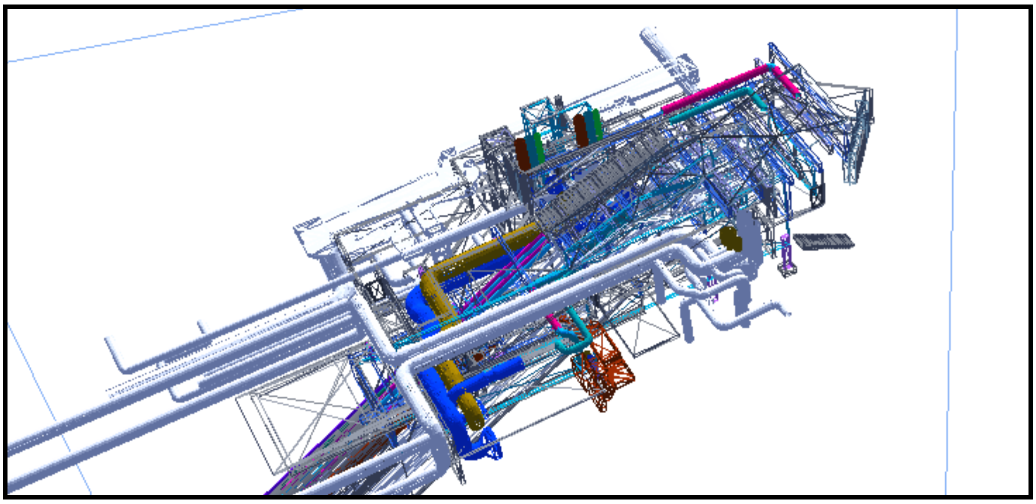
The City Rail Loop will make the city center more accessible with trains running directly to Töölö and Hakaniemi. It will also improve the connections to the Olympic Stadium, the Helsinki Ice Hall and the Opera and draw more customers to the businesses in the area. (Finnish Transport Agency)



Picture 2 Total model of the City Rail Loop (Finnish Transport Agency 2015)

The case project involves infrastructural construction, housing construction in the station parts and it is mainly situated underground. The projects cost estimation is close to 1 billion euros. The project involves 15 different design disciplines with a rough division, 300 designers and 100 other consultants and officials..

In this project there was a decision made to design the project in building information modeling environment by FTA and city of Helsinki. FTA and city of Helsinki decided to make City Rail Loop a project where BIM based design practices are developed (City Rail Loop Project Plan). City Rail Loop developed a BIM strategy together with the designers to achieve these goals that were set to project and minimize the risks that relate to the use of modeling in the project.



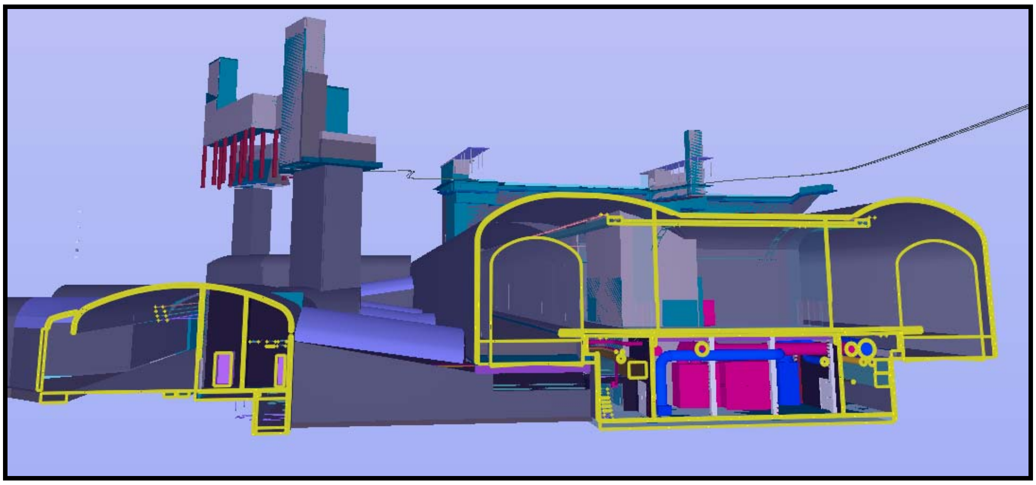
Picture 3 Example of detailed modeling in City Rail Loop (Finnish Transport Agency 2015)

City Rail Loop BIM strategy was produced to gather all the goals for modeling and purposes of use for the models. Strategy points the ways to achieve these gathered goals. Strategy is a way to communicate these goals and ways to achieve them to all the different parties involved in the project. (City Rail Loop BIM Strategy)

To achieve the goals developed in the City Rail Loop BIM Strategy describes:

- requirements for different parties
- resources needed for modeling
- roles and responsibilities
- information to be produced that supports decision making
- information to be produced that supports that works as a upkeep document in the operation and maintenance phase
- how service provider can assist on reaching the set goals
- how it works as a part of preparation of offerings

As a result of the strategy the project formed an information model development group that shares developed practices in different procurements. The group also brainstorms new ways of working and the best practices to be used in this project.



Picture 4 *Cross-section of the City Rail Loop model (Finnish Transport Agency 2015)*

This project will serve as a source of data for this master's thesis.

1.3 Goals of the Master's Thesis

In this master's thesis the goals are to study what are the current good design management practices and processes that are used. This includes researching the collaboration methods and processes that are used in the case project and in literature. Through analyzing literature, following project meetings and doing interviews the goal is to define opportunities for further improvement.

1.4 Research Questions

The goals of the master's thesis result in following research questions:

- What is the current BIM process and how could the current BIM processes be developed?
- What is done well in the current BIM design process?
- What should be the BIM process to produce models and information efficiently and compatibly?

Answers for the first questions are found from the literature research as well as from the empirical section of this thesis. The researched theories give sight on the current process of BIM design in theory. Also following the meetings and doing interviews will tell how the process is executed now in this case project. In the research question, BIM processes mean both information and work-flow processes.

The following question concerning the current BIM process is hoped to be answered through the interviews. The answers for this question are the result of the interviewee's experience of case project and other projects.

The third question will be answered through empirical data and all new techniques introduced in the theory.

1.5 Structure of the Master's Thesis

This master's thesis consists of four main parts. They are theory research, collecting and analyzing empirical data, findings and conclusions.

In theory/literature research the latest theories and models for co-operation design methods are studied. In analytics of empirical data following meetings, gathering interviews and other empirical data are presented. In findings the results of these two parts are combined. In conclusions the results of this master's thesis are presented and evaluated.

1.6 Research Framework and process

The research of the case project was done during the end of the preliminary design phase. This is why the research framework is also mainly around preliminary design phase. From the empirical data and theory there also rises research that refers to a wider framework. There subjects cover also design in more detail design phases.

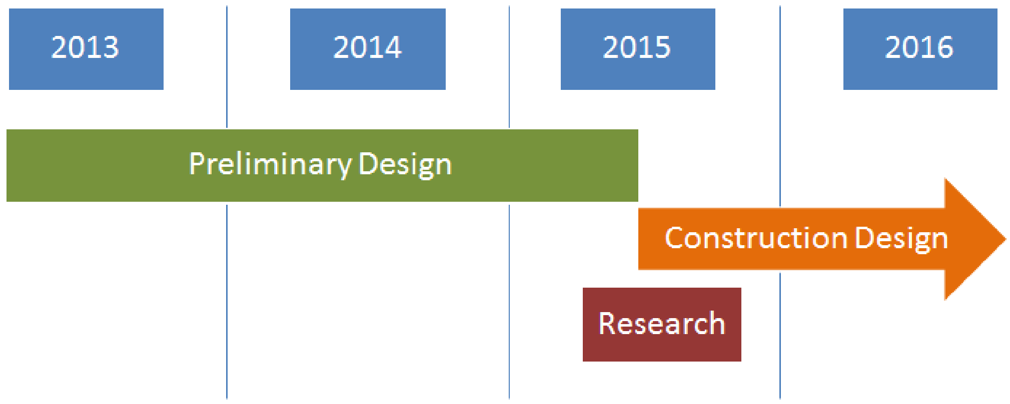


Figure 2 Research in the case project timeline

Research process was a bit different from a traditional process of a master's thesis. Usually a master's thesis starts with a literature research. In this thesis due to the case project's schedule, the empirical data was collected first. The empirical data was collected in the end of the preliminary design phase. This was done because it was hoped to give results to improve the design process of the construction design phase. It was also a time when the project's teams were collaborating to produce compatible models. This was found to be beneficial for the thesis. The research process of this thesis can be seen in the figure below.

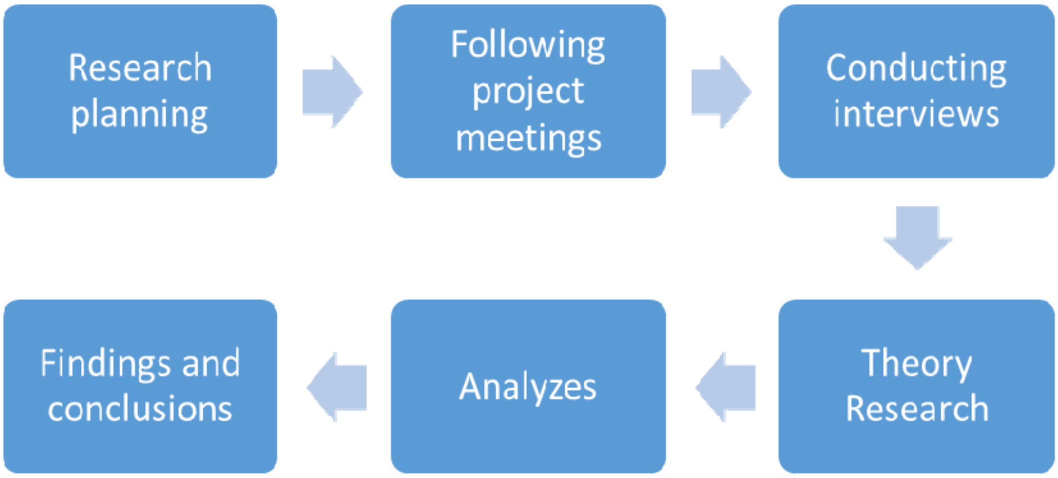


Figure 3 *The research process*

2 Theory and description of previous knowledge

Literature research is required in the master's thesis. This literature research investigates BIM guidelines, BIM standards, Lean construction and knotworking. BIM guidelines and standards were selected based on their language. All the revised guidelines are written in English. These selected guidelines were researched on their approach to BIM processes: planning and execution. Guidelines and standards were selected for review to find if they contain new information for BIM processes in comparison to previous knowledge in the case project. Guidelines also give insight on the BIM implementation to a project. Guidelines and standards outside Finland were also researched to see if they would give more precise instructions for the processes than the Finnish guidelines.

Other aspect of the literature research is the general process literature. These include Lean construction and knotworking. They are general process development tools to help problem solving in the project as well as to increase workflow and decrease waste in the process. They were selected because they are the latest process development tools introduced to the construction industry.

2.1 BIM Project Planning and Execution

This part of theory research studies different guidelines and standards for BIM processes. It researches the implementation of BIM in the project and the process of using it in design.

In the researched guidelines and standards the process for BIM implementation and design is quite similar. The chapter is written in the form of this process. Different guidelines are referred based on which guideline gives the best and the most accurate descriptions of each phase of BIM based design process. The process starts from execution planning and continues to the co-operation and sharing the information in the design phase. The chapter covers the subjects that need to be planned in the project in order for it to be successful in each phase. This is the essence of the guidelines and standards.

"Building Information Modeling (BIM) is a process focused on the development, use and transfer of a digital information model of a building project to improve the design, construction and operations of a project or portfolio of facilities." (Messner, et al. 2011)

First phase in implementing BIM to projects design is to develop an execution plan. Guides Messner et al. (2011), the VA BIM Guide (2010), AEC (UK) BIM Technology Protocol (2015) and Singapore BIM Guide (2013) state that to implement BIM, the project team must perform detailed and extensive planning. This BIM execution planning (BEP) should be performed at an early stage of a project. The plan should include opportunities, responsibilities and documentation of the process.

Guide by Messner et al. (2011) provides a procedure with following steps:

1. Identify high value BIM uses during project planning, design, construction and operational phases
2. Design the BIM execution process by creating process maps
3. Define the BIM deliverables in the form of information exchanges
4. Develop the infrastructure in the form of contracts, communication procedures, technology and quality control to support the implementation

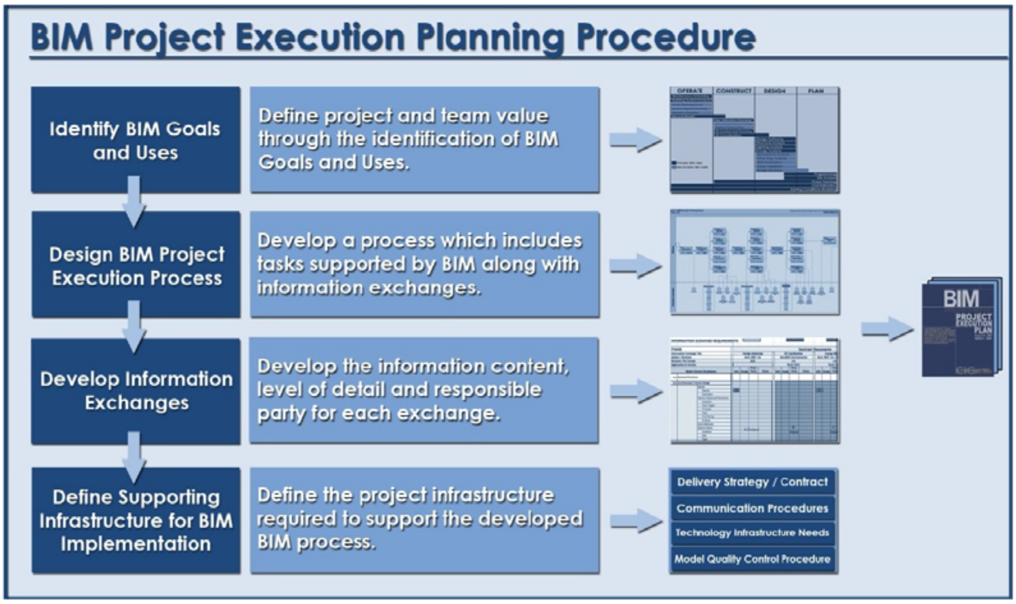


Figure 4 BIM Project Execution Planning Procedure (Messner et al. 2011)

In addition to BIM Project Planning Guide (2011), AEC (UK) BIM Technology Protocol (2015) lists the following things to be included in the BIM execution planning:

– **Goals and Uses**: Define the project's BIM goals, uses and aspirations along with the workflows required to deliver them.
– **Standards**: The BIM standard used in the project and any deviation from that standard.
– **Software Platform**: Defines BIM software to be utilized and how interoperability issues will be addressed.
– **Stakeholders**: Identifies project leadership and additional stakeholders and their roles and responsibilities.
– **Meetings**: Defines the BIM meeting frequency and attendees.
– **Project Deliverable**: Defines the project deliverable and the format in which it is delivered and exchanged.
– **Project Characteristics**: Number of buildings, size, location etc. Division of the work and schedule.
– **Shared Coordinates**: Defines the common coordinate system for all BIM data. Details modifications to imported DWG/DGN coordinates.
– **Data Segregation**: Addressing model organizational structures where relevant to enable multi-discipline, multi-user access and project phasing as well as ownership of project BIM data.

- **Checking/Validation**: Defines the checking/validation process of drawings and BIM data.
- **Data Exchange**: Defines the communication protocols along with the frequency and form of data exchange.
- **Project Review Dates**: Sets out key dates for reviews of the BIM which all teams buy in to (both internal to the company and externally with the full design team).

Project must be reviewed according to the BEP. These reviews must take place regularly. This ensures that models fulfill quality requirements, project achieves goals, workflow is maintained and BEP is being followed and developed. (AEC UK BIM Technology Protocol)

Richards et al (2013) divide the execution plan to two separate phases: pre-contract and post contract. Reason for separation is that some of the content has to be agreed with the contracted designers and engineers. Content of the pre-contract execution plan is:

- Project information
- Employers information requirements
- Project implementation plan
- Project goals for collaboration and information modelling
- Major project milestones
- Project information model (PIM) delivery strategy

Content of the post contract execution plan is:

- Project information
- Employers information requirements
- Management
- Planning and documentation
- Standard method and procedure
- IT solutions

PAS 1192-2:2013 also emphasizes making a document of employer's information requirements (EIR) before continuing to the phase of developing BIM execution plan. This includes collaborative working requirements and definition of information exchange. EIR is formed on the base of project execution plan.

Next stage in the BIM process is creating the models and sharing of the information according to the execution plan. Individual designers first produce their models according to the minimum standard of modelling requirements. These requirements need to be decided in the execution plan. These models are then validated and quality checked for the use of other designers. After validation the revision is frozen and released. Validation is a process to make sure that models are fit for cooperation between disciplines. (Singapore BIM Guide 2013)

An alternative process for publishing combined models is demonstrated in a master's thesis by Jaakko Kinnari (2013). In this process the suggested format is IFC and the process of publishing is as is shown in the figure below.

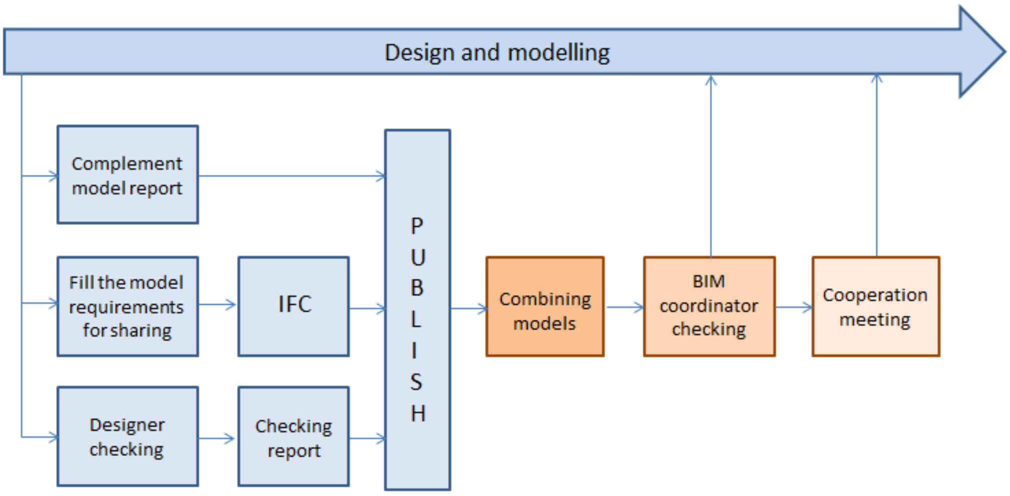


Figure 5 Process of publishing models (Kinnari 2013)

Models are rapidly changing through the project. A system for following these different revisions must be adapted to the process. Changes should be tracked and documented. This is especially important when models are created by several people. This is a task that the BIM coordinator of each discipline is responsible for. (Singapore BIM Guide 2013)

2.1.1 Collaboration and information management

Produced models are needed by other disciplines to be used as a reference to their own design. Sharing of models should be done on regular intervals. Other cooperation exists also in the project. This needed cooperation should be mapped. This mapping should show interactions between different disciplines. Different software solutions are available to effectively collaborate. Problems in the collaboration should be recorded and communicated to project parties. These collaboration methods should then be changed accordingly. (Singapore BIM Guide 2013)

	Employer	Architect	Consulting Engineers	Contractor / Quantity Surveyor
Conceptual Design	Provide requirements related to form, function, cost and schedule	Begin design intent model with massing concepts with site considerations	Provide feedback on initial building performance goals and requirements	Provide feedback on initial building cost, schedule, and constructability *
Schematic Design	Provide design review and to further refine design requirements	Refine Design Model with new input from Employer, Consulting Engineers, and Construction Manager	Provide schematic modelling, analysis and system iterations as Design Model continues to develop	Provide design review and continued feedback on cost, schedule and constructability*
Detailed Design	Design reviews. Final approval of project design and metrics	Continue to refine Design Model. Introduce consultants models and perform model coordination	Create Discipline-specific Design Models and Analyses	Create Construction Model for simulation, coordination, estimates, and schedule*
		Finalize Design model, Tender Documents and Specifications, Regulatory Code Compliance	Finalize Discipline specific Design Models, Tender Documents and Specifications, Code Compliance	Enhance Construction Model and perform final estimate & construction schedule, Manage bid process

Table 1 Example of BIM project collaboration map in design phase (Singapore BIM Guide 2013)

Other means of collaboration management is provided in the British standard BS 1192:2007. It notes that the projects should follow standard processes that are then tuned project-by-project. This is the case especially when processes are those that describe the production of design. These include co-ordination of the project model files and production of drawings and models. These processes should be agreed on the early phases of the project by relevant parties of the project.

Standard BS 1192:2007 and PAS 1192-2:2013 describes a common data area (CDA) that should be conducted for the sharing of information. The standard divides it to four parts: work in progress (WIP), shared, published documentation and archive.

Work in progress section is for the use of in-design team. It consists of different drafts, concepts and versions. Each file in WIP should be work and responsibility of a single design team. Versions are evolving in WIP area and they should be tracked with filename index.

Shared data includes information that is needed for coordination and cooperation. Here is where the ongoing design development happens. Shared environment can be separated to include project team are and client area. A file is moved to shared area when its classification is changed to fit for cooperation. To achieve this classification file must be checked by authorized person of the design team. The standard suggests this person to be the lead designer. These procedures prevent working with adversarial documents. It is also important to download models and files just once to shared area. Duplications of information can cause problems. Duplicate layers or parts in different models should be removed before uploaded to shared area. For example structural and architecture models could include duplicate parts in the work in progress area. New files or versions should also be tracked with a revision indicator. (BS 1192:2007)

Published documents are information that for example fit the requirements of tendering, costing, manufacturing, construction. These requirements set milestones for published document publishing. They are determined in the schedule of the project. When shared documents meet these requirements they need to be authorized by the client. After client approval they can be shared and stored in the published document section. (BS 1192:2007)

Archive provides classification for knowledge of project history. Archive can also include every other kind of information that is not related to previously mentioned information. Material can include legal material, history of information transfers, operation and maintenance information. (BS 1192:2007)

BS 1192:2007 also recommends using file classification system. A simple code is attached to the file to classify the file and give information about the content and its readiness. Different classifications are needed for file to switch from directory to another. For example file classified as B could mean ready for shearing. B then tells that the document fulfills the set list of requirements to get its classification. One useful classification is needed for quick information requests. These means that the document could be transferred to published documentation but the classification tells that it only fulfills this quick information request. For example it is not ready to meet the construction document classifications.

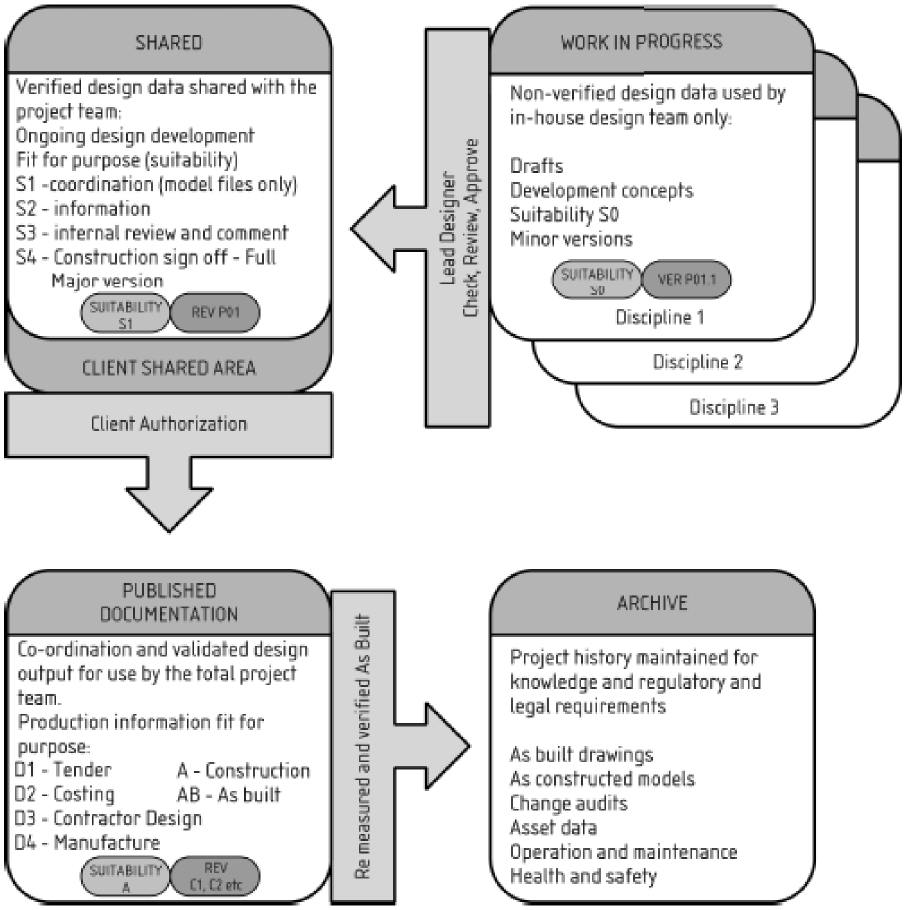


Figure 6 Common Data Area (BS 1192:2007)

Other terms classification needed for information is the status of file. This should implicate the suitability of information to defined purposes. Classification is also needed for the designers. This refers on giving a role and a definition of the role for each member of the project team. Member of the team should be a part of at least one role. (BS 1192:2007) PAS 1192-2:2013 gives an example of status code definitions as shown in the table below.

Status	Description
Work In Progress (WIP)	
S0	Initial status or WIP Master document index of file identifiers uploaded into the extranet.
Shared	
S1	Issued for co-ordination The file is available to be "shared" and used by other disciplines as a background for their information.
S2	Issued for information
S3	Issued for internal review and comment
S4	Issued for construction approval
S5	Issued for manufacture
S6	Issued for PIM authorization (Information Exchanges 1-3)
S7	Issued for AIM authorization (Information Exchange 6)
D1	Issued for costing
D2	Issued for tender
D3	Issued for contractor design
D4	Issued for manufacture/procurement
AM	As maintained
Published documentation	
A	Issued for construction
B	Partially signed-off: For construction with minor comments from the client. All minor comments should be indicated by the insertion of a cloud and a statement of "in abeyance" until the comment is resolved, then resubmitted for full authorization.
AB	As-built handover documentation, PDF, native models, COBie, etc.

Table 2 Status term codes in the CDE as in PAS 1192-2:2013

Under these kind of status definitions it can be defined by discipline the collaborative needs for each element produced. These kind of definitions help to prioritize the design and to achieve better quality of the collaborative models. (Singapore BIM Guide 2013) Below is given an example of simple table to make these definitions.

Table 3 Example of how to simply define the parametric needs of each model element by discipline

(II) STRUCTURAL BIM ELEMENTS

Element	Elements or Parameters needed by each non-Structural discipline
Foundations including piles, pile caps, tie / ground beams & footings	
Diaphragm walls & retaining walls	
Beams	
Columns	
Walls	
Slabs, including slab on grade and floating slab, recesses, curbs, pads and major penetrations	
Other types of transfer structure not mentioned above	
Stairs (steps, risers, threads, landings): all framing members and openings	

BS 1192:2007, PAS 1192-2:2013 and other guidelines also emphasize the importance of standardized naming practices. Files and folders naming should be consistent and based on a national standard and extended with project specific naming standards. Same goes with the naming of spaces and layers.

Grids and origin should be agreed on between the project team members on an early phase of a project. (PAS 1192-2:2013 and BS 1192:2007)

Nevertheless, the building information is more than just the visual model as described in the British standard PAS 1192-2:2013. It actually involves all documentation, non-graphical data and the graphical model. The amount of this information increases as the project forwards. This is why the planning of information delivery and formats needs to be taken in to consideration in the project. This is what the actual collaboration in the project is.

An important area of information is also volumes. Project should provide a strategy to communicate volumes to team members. This enables concurrent working with models. Volumes can be based on structure of cores and HVAC systems. These are important parts of the design. Clashes are not allowed for volume objects. Volumes are the responsibility of the designer. (PAS 1192-2:2013)

In addition to previous classifications for shared documents the accuracy of models in each stage of the design should be planned (AIA Document E203 – 2013). This kind of classification is needed because as the components and systems in design progress, the level of detail is not simply looking at the model. It is easy for the author to know it but it is also easy for others to misinterpret it. Risk is that a measure in the model is referred as exact when the author has just given an approximation. (LOD Specification 2015)

This kind of specification for Level of Development (LOD) is given in the document LOD Specification 2015. LOD compiles of six clearly interpreted categories:

> **LOD100**: Symbols in the model can show an existence of a component. Symbol doesn't indicate the size, shape or precise location. Every part of LOD100 must be considered as approximate data. LOD100 is not a geometric presentation of a structure.
>
> **LOD200:** Model Elements are modeled as generalized systems or assemblies with approximate quantities, size, shape, location, and orientation. Non-geometric information may also be attached to Model Elements. LOD200 indicates a generic placeholder. They can be recognized as the component or system they represent. They also could be just volumes or space reservation. Every piece of LOD200 information is approximate.
>
> **LOD300:** Model Elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation. Non-geometric information may also be attached to Model Elements. All these mentioned elements can be measured from the model without using notes or dimension call-outs.
>
> **LOD350:** In addition to LOD300 the needed coordination parts for the element are also presented. These parts include supports and connections.

LOD400: Model Elements are modeled as specific assemblies that are accurate in terms of size, shape, location, quantity, and orientation with complete fabrication, assembly, and detailing information. Nongeometric information may also be attached to Model Elements. LOD400 accuracy fulfills the needs for fabrication of the specific element.

LOD500: Model Elements are modeled as constructed assemblies actual and accurate in terms of size, shape, location, quantity, and orientation. Non-geometric information may also be attached to modeled elements.

Level of development classifications have many development phases also between them. This is why they should be considered as minimum requirements. LOD specifications are cumulative. This means that if an element fulfills the requirements of LOD300 it must also fulfill the requirements in LOD100 and LOD200. LOD levels vary from project to project and that is why they should be defined again in each project. LOD Specification 2015 gives a listing of suggested detailed specifications for each building element. (LOD Specification 2015)

Below is given an example of LOD specification for a single model element from LOD specification 2015:

Table 4 Example of accurate LOD definitions for a single model element

A10 Foundations

100	Assumptions for foundations are included in other modeled elements such as an architectural floor element or volumetric mass that contains layer for assumed structural framing depth. Or, schematic elements that are not distinguishable by type or material. Assembly depth/thickness and locations still flexible.
200	Element modeling to include: • Approximate size and shape of foundation element • Structural building grids for local project coordinate system are defined in model and coordinated with global civil coordinate system (State Plane Coordinate System, etc).

A1010 – Standard Foundations

100	See A10
200	See A10
300	Elements are modeled to the design-specified size and shape of the foundation. Element modeling to include: • Overall size and geometry of the foundation element • Sloping surfaces or floor depressions • External dimensions of the members Required non-graphic information associated with model elements includes: • Concrete strength • Reinforcing strength

LOD classification can be connected to the BIM elements in a simple listing called model element table. In the table the LOD level is defined for each element in each phase of the design. In this table the author (MEA) of each element as the LOD level are defined for each design phase. An example can be found below. It should be noted that is only defined the minimum content requirements and the actual models can be modelled at greater detail. (AIA E203 2008)

§ 4.3 Model Element Table

Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.

Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."

NOTE: LODs must be adapted for the unique characteristics of each Project.

Model Elements Utilizing CSI UniFormat™					LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	Note Number (See 4.4)
A SUBSTRUCTURE	A10	Foundations	A1010	Standard Foundations													
			A1020	Special Foundations													
			A1030	Slab on Grade													
	A20	Basement Construction	A2010	Basement Excavation													
			A2020	Basement Walls													
B SHELL	B10	Superstructure	B1010	Floor Construction													
			B1020	Roof Construction													

Table 5 Example of model element table (AIA E203 2008)

2.1.2 Other best practices in BIM processes

Here are collected other best practices that are not noted previously in this chapter.

AEC (UK) BIM technology protocol lists these best practices to be used in the model producing process:

- It is imperative for smooth information exchange that clear guidelines are developed for internal and external collaborative working which maintain the integrity of electronic data. This is equally important for employer's decision points, suppliers' information exchange and the iterative model exchange of design data between these more formal deliveries.
- Identify clear ownership of model elements through the life of the project.
- Sub-divide models between disciplines and within single disciplines to avoid file sizes becoming too big or slow to operate within the agreed project volume strategy.
- Understand and clearly document what is to be modelled and to what Level of Detail (LOD). Do not over model.
- Define clearly the data (Level of Information (LOI)) to be incorporated into the BIM relevant to the stage.
- Together, the LOD and LOI help to better communicate the expectations of BIM content and clarify the Level of Definition at any point in the design and construction process. Level of Definition = LOD + LOI
- Avoid disconnect between the main 3D model and 2D views or output. Revisions to the project should be made "at source" (i.e. in the model) to rather than editing the 2D to ensure the integrity of the model and coordination between the BIM and its output.
- Outstanding warnings shall be reviewed regularly and important issues resolved.
- Where drawings are a product of the BIM, traditional drawing conventions still apply.

2.1.3 Summary of BIM execution and planning

Previous chapter covered the BIM execution and planning. The researched guidelines and standards were good in giving answers for what needs to be planned in BIM based project for the implementing to be successful. The referred material was also good at giving lists of things to be taken into consideration.

All of the guidelines were good on the level what is needed to be planned. They didn't refer to good examples and they were written in very general level. There would have been a need for more accurate process descriptions. The description of how to share models and information was in a high level. On the other hand guidelines for model accuracy on each phase of the project were missing. This kind of definitions would be really useful for the users of guidelines.

Many of the existing guidelines cover well housing building but only few cover infrastructure modeling. So there is a need to develop BIM guidelines for infrastructure engineering and the BIM collaboration between infrastructure and housing engineering.

The referred guidelines have differences in comparison to Finnish guidelines. For example the Finnish guidelines (YIV 2012) leave the BIM process open and the referred guidelines cover these matters in changing accuracy. For example the referred British guidelines give quite exact process description but leave open how that process can be achieved. The Finnish on the other hand gives possibilities on what can be done with BIM and leaves the process for the projects to decide.

The guidelines model producing process can be summarized to follow the figure below.

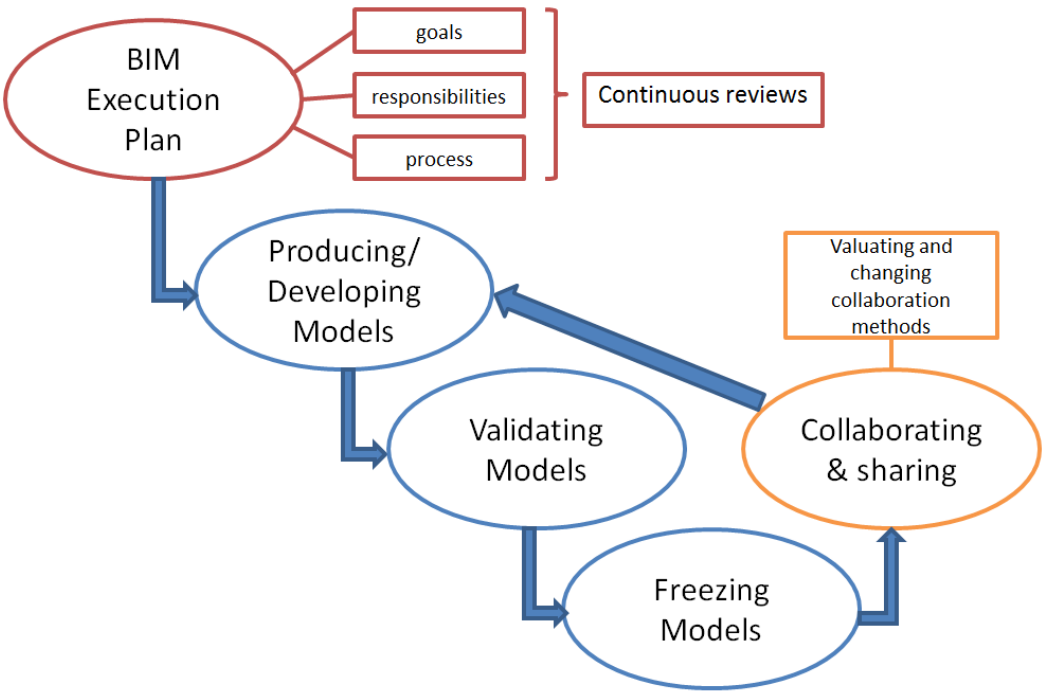


Figure 7 Model producing process according to the researched guidelines

All the guidelines suggest this kind of process for producing models. They might differentiate in details.

Guidelines had their differences. Some were more specific on certain matters than others. In the following part there are gathered short reviews on each of the referred guidelines:

National Guidelines for Modelling Australia 2009

Australian national guidelines were not in very specific level. In this guideline there were mainly gathered possible uses for BIM in projects. It could be a good starting guideline for someone, who has just started working with BIM issues. Higher level BIM professionals would need a more specific guideline for managing the design process. It is a bit outdated to be used as a only guideline for current projects.

Level of Development Specification 2015 (BIM Forum)

This guideline offers the best guideline to refer for LOD specification. The need for LOD is explained well. Guideline also provides hands on tables for each construction element LOD specification. This provides a very good starting point for any project to develop LOD specifications. Guideline didn't present an example for different LODs in different project phases. Guideline covered only housing engineering. LOD guideline for infrastructure engineering BIM elements would be needed.

Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors 2011

This is a good basic guideline. Best parts of it are the required deliverables in each design phase, which can be used a base for any project. It also provides good process charts on how to validate models in each phase of the project.

AEC (UK) BIM Technology Protocol 2.1

This guideline is one of the best guidelines in implementing BIM. This is a must read for anyone co-operating with BIM or managing BIM processes. It provides complete listings for co-operation, sharing and other BIM requirements in a project. Represented BIM processes can be used in infrastructure engineering.

Singapore BIM Guide 2013

Guideline gives a good framework for BIM collaboration and information production. It also gives a very god listing for defining the collaborative needs for each building element.

BIM 'Best Practices' Project Report University of British Columbia 2011

This paper researches BIM practices from case studies. Guidelines researched in this paper are already quite outdated. Possible uses of BIM and other BIM practices through case studies are a good source of BIM information. Evaluation of each case project with areas of benefits, challenges and lessons learned is a good read.

British Standard 1192:2007

Headline of this standard is Collaborative production of architectural, engineering and construction information – Code of practice. This standards is good to refer in model sharing practices. It covers a classification system for deliverable information and a process for collaboration.

PAS 1192-2:2013

Headline of this guideline is Specification for information management for the capital/delivery phase of construction projects using building information modelling. This guideline is extremely good in the viewpoint that it recognizes the need of all model related information co-operation. In BIM other deliverables are also needed and this guideline provides well explained processes on how to do just that.

VA BIM Guide 2010

This is an general level guide. It doesn't go to a great level of detail.

BIM Project Execution Planning Guide 2.1 2011

This is a extensive guide for implementation and performing project execution plan. This guide is recommended referring material for BIM projects. It gives good outlines for information exchanges and identifying BIM goals and uses. It also defines how to create a supporting infrastructure and how to implement BIM to a project.

Pre/Post Contract-Award Building Information Modelling (BIM) Execution Plan (BEP)

These guidelines go through the needed content for BIM execution plan in narrow level. Mostly things needed to be included in the plan are gone through on a headline level with short descriptions.

In short the best guidelines to cover following topics were:

General guidelines:

- National Guidelines for Modelling Australia 2009
- Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors 2011
- VA BIM Guide 2010
- Singapore BIM Guide 2013

Information sharing and collaboration:

- British Standard 1192:2007
- PAS 1192-2:2013
- Singapore BIM Guide 2013

Model Accuracy:

- Level of Development Specification 2015

Execution planning

- BIM Project Execution Planning Guide 2.1 2011
- Pre/Post Contract-Award Building Information Modelling (BIM) Execution Plan (BEP)

This chapter provided insight to specific BIM guidelines and what they have to offer to support design management. Next chapters revise other kind of methods for developing and managing processes.

2.2 Lean construction

Last part of the theory described guidelines to avoid practical problems in the BIM producing process. Guidelines give solutions for everyday project information transfer and sharing practices. Next chapters focus more on the management side of the design process. Lean, integrated project delivery, concurrent engineering and knotworking are systems and philosophies to better manage the design and to create value for customer.

Definition of LEAN

"There is considerable confusion regarding what is meant by lean, lean construction and lean design in the extant literature, with many competing definitions and interpretations. Typically definitions are implicit vague, interpretative and/or based on references that eventually lead back to popular management literature. Mostly word lean is used to systems that are inspired by the original lean rather than being straight copies of the original one." (Jorgensen, Emmit 2009). This is why in this thesis Lean is defined as a general definition as follows.

Lean is production development philosophy that is based on the Toyota Product Development System. It emphasizes maximizing flow efficiency and resource efficiency and how both of them could be achieved. (Modig, Åhlstrom 2013) In their book Modig and Åhlstrom describe that main principles in achieving these goals are minimizing waste in the process and adding value for the customer. The seven wastes defined in Lean is shown in the picture below. This Lean cannot be applied straight from manufacturing industry to the construction industry due to the basic differences in their production. This has led to the development of a concept and theory of Lean construction.

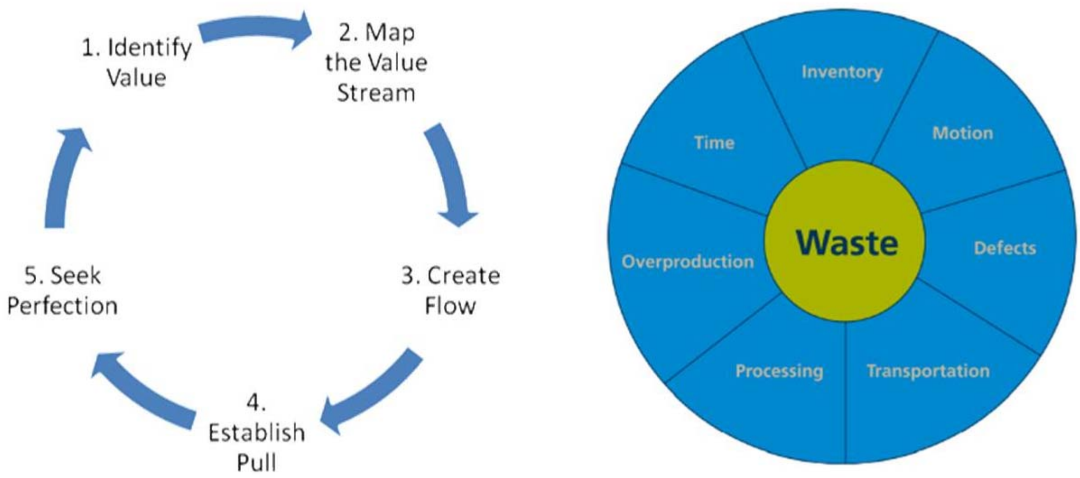


Figure 8 Key Lean principles and seven wastes of Lean

Definition of Lean construction

"Lean construction refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. As in the TPS, the focus in lean construction is on reduction of waste, increase of value to the customer, and continuous improvement. While many of the principles and tools of the TPS are applicable as such in construction, there are also principles and tools in lean construction that are different from those of the TPS." (Sacks, et al. 2009)

Lean construction differs from TPS. The wastes mentioned earlier have been defined to better comprehend with construction industry in Lean construction as follows (Howell 2014):

1. Oversupply
2. Down-time/delays.
3. Delivery scheduling delays and inadequacies.
4. Waste inherent in physical construction (also related to estimation).
5. Storage on site.
6. Inadequate site planning
7. Re-work and quality

Last Planner

Last Planner was chosen in this thesis under more accurate research due to its wide use in the industry. There have been good results achieved with the use of Last Planner. The process of last planner is mainly described here as it was executed in the case Cathedral Hill Hospital project. This was done because the process is really well presented through figures in the paper of Hamzeh, Ballard and Tommelein (2009). This was found uselful for this thesis.

To prevent wastes mentioned previously Last Planner production control system was developed in the USA during 1990's. It is a system that focuses on short period planning and management in the construction site. The central concept is to increase work flow and map dependencies between tasks. One part in Last Planner is preparing planning four to six weeks ahead. Its purpose is to make sure all the conditions and resources needed to start a task are fulfilled. The system follows the number of planned and finished tasks and their relation. If task is not fulfilled the purposes are examined. These purposes and analyzing them give sight in developing the construction process and preventing of these purposes. (Koskela, Koskenvesa 2003)

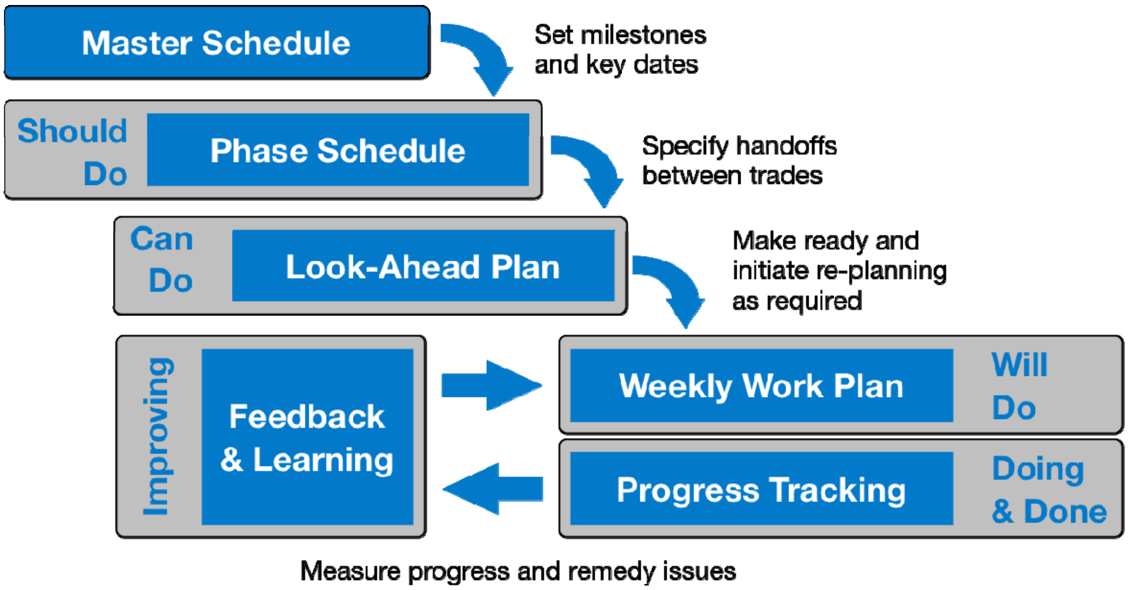


Figure 9 *Last Planner System (Ennova)*

The Last Planner system of production control can be characterized in terms of the principles that guide thinking and action, the functions it enables to be performed, and the methods or tools used to apply those principles and perform those functions. (Ballard et al. 2009) These principles, functions, methods and tools are shown below.

Principles:

- Plan in greater detail as you get closer doing the work
- Produce plans collaboratively with those who will do the work
- Reveal and remove constraints on planned tasks as a team
- Make and secure reliable promises
- Learn from breakdowns

Functions:
- Collaborative planning
- Making ready: constraints idenfication and removal, task breakdown, operations design
- Releasing
- Committing
- Learning

Methods and tools:
- Reverse phase scheduling aka pull planning, visalization with stickies-on-a-wall
- Constraints analysis; constraint logs; risk registers
- Task hierarchy: phase(process(operation/steps
- First run studies
- Daily huddles
- Reliable promising
- Metrics: percent plan complete, tasks made ready, tasks anticipated
- 5 Whys analysis

Adaptation and comparing the use of traditional production planning system and Last Planner system had been widely researched. Implementing Last Planner to production planning gave good results in increasing the amount of planned assignments completed. Research done in USA, Chile, Brazil and Denmark showed a 10–70 % increase in productivity when Last Planner was used in construction projects. When system was implemented to Finnish construction projects the results were also good. Implementing the system gave an average of 16 % rise in completed weekly assignments. (Koskela, Koskenvesa 2003)

Last Planner in design

Last Planner was designed for construction sites but adapting the system to the design process has also been researched. The nature of construction design is iterative and managing is this process is often executed by the push method mentioned earlier. Applying Last Planner with modifications to meet the needs of design process tries to take this managing of schedule to pull method and make workflow from iterative to continuous method. (Hamzeh et al. 2009)

These iterations that are being made in the design process can be value adding or wasteful. Foreseeing which iterations have negative impacts and which don't is very difficult. Design process comprises complex tasks that entail reciprocal interdependencies and require sharing of incomplete information. (Ballard et al. 2009) One feature of design process is also high variability that affects managing workflow. In his paper Ballard et al. (2009) highlight three main factors that distinguish production control during design: (1) greater uncertainty of ends and means reducing the ability to foresee the sequence of future tasks, (2) the impact of increasing execution speed of design tasks on removing constraints and making tasks ready for execution, and (3) interdependencies between design tasks that increase work complexity and the planning functions. To reduce the effect of these factors Last Planner advocates the principles mentioned in the listing above.

In their paper Hamzeh, Ballard and Tommelein (2009) research implementing the Last Planner to design process. In the case project Last Planner integration was well planned and executed. The road map for applying last planner was the first thing to do. Key element for implementing the new management system was training the designers in the use of Last Planner. Then the project team produced the process map for the planning process. The process is shown below.

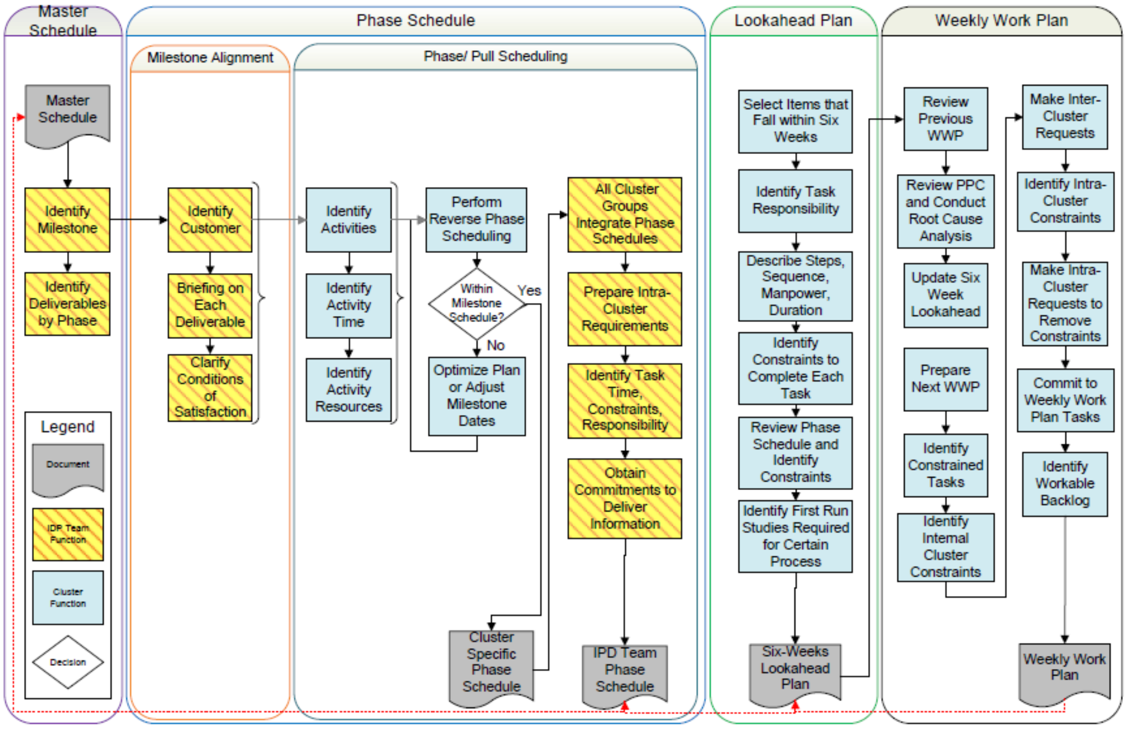


Figure 10 Process Map Depicting the Planning Process at CHH (Ballard et al. 2009)

The planning starts from Master Schedule where all the key milestones are identified. These milestones are then aligned. Activities to reach these milestones are then identified. The resources and time needed to perform these activities is researched. As a result of these identifications the reverse phase scheduling can be done. From the results of scheduling it is checked if they still match with the milestones. If they are not matching then the milestones or activities are modified. As a result of this process cluster specific phase schedule is produced. Next phase in the case projects process map is to produce integrated project delivery teams phase schedule. This part may not be compatible with other projects not using IPD.

After these schedules the management is taken to a more precise level. Lookahead Plan is produced by selecting the items that from previous plans fall for this time period. Tasks are identified and analyzed. Task analyzes include identifying responsibilities, steps, sequence, resources and duration. Constraints and first run studies needed for completing task are identified. After these tasks are analyzed the result is six week lookahead plan. From the lookahead plan the planning is taken to more specific level when the weekly work plan is made.

In the weekly work plan the last weeks plan is reviewed. The measurement tools of the Last Planner are now implemented and analyzed. Planned percent complete (PPC) tool is measured and the root causes for not completing the tasks planned are analyzed. From these analyzes the project team learns and can improve their planning in the future.

Information flow

Planning the schedule and the process is not enough to have a good management over the project. Many different planning meetings are held inside the project. Project parties also need to design the flow of information inside the project and between different meetings. In CHH project they had developed a visual process chart to show the necessary information flows between clusters and different cyclical meetings. This visualization is shown in a figure below.

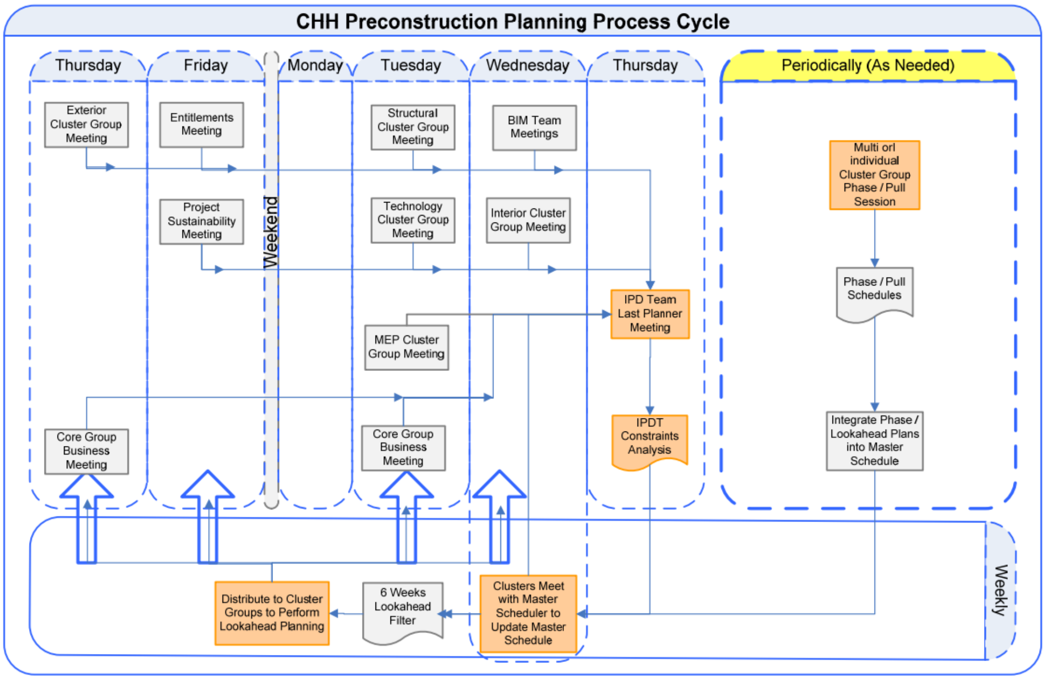


Figure 11 *Information Flow Model for Planning Process at CHH*

Integration in Finland

Last Planner implementation has also been tried in Finland. In their paper Kerosuo et al. (2012) research the subject from viewpoint of Finnish construction design projects. They followed he meetings that the design groups held during the design process and compared the method used before and last planner method. Their one finding was that before LP the design team was lacking a controlled and systematic listing of different design tasks and problems that possibly impede the design. There was a lack of routine to handle these problems. Implementing LP resulted in changes in collaboration practices inside the design group. One of the changes was that the meetings moved from formal meetings towards meetings with emerging agenda.

Interaction of lean and BIM

In the paper of Mäki et al. (2013) were also comparison the traditional method with LP approach in BIM based design project. Adapting Last Planner system to the design processes of a Finnish construction design project had advantages compared to the systems that were used before. Using Last Planner increased collaboration and change of information between designers. Last Planner increased the amount of completion of tasks that were agreed on. Most of the designers found Last Planner beneficial in their work.

Interaction of BIM and lean has been researched by Sack et al. (2009). They made a literature review of BIM and lean properties supporting and impeding each other. Although lean and BIM are two separate issues they found out that there are possible synergy possibilities. Research's finding was also that the three lean organizational viewpoints have all been researched individually in AEC industry but not as a whole. When researching synergies, research group created a matrix of BIM and lean practices supporting and impeding each other. The matrix and tables can be found from the appendix.

Value Stream mapping (VSM)

Last planner is not the only tool researched under lean construction. Other tools developed from TPS used in AEC industry are value stream mapping, A3-problem solving technique and '5 x why'- method. Value stream mapping is a tool to analyze a process and the parts of it that are actually adding value. Value stream mapping visualizes the process and then defines the parts that are value adding for the product in the process. This value adding time is compared to the time of the whole process. When they are compared, it results in knowledge on efficiency of the process. From VSM it is easy to interpret the bottlenecks and wastes in the process. First current-state map is produced and analyzed. Second future-state map is planned. Method has been tested in construction in Yu et al. (2009) and Rosenbaum et al. (2014) which resulted in decreased total duration. Research in applying the system to construction design was not found.

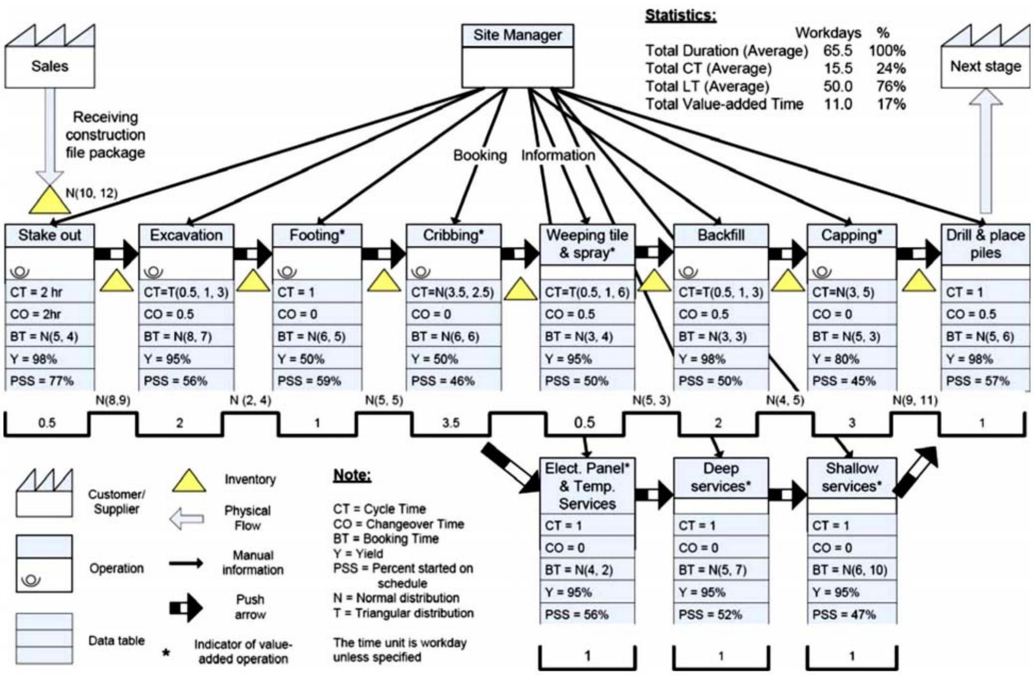


Figure 12 *Example of value stream mapping (Yu et al. 2009)*

A3 Problem solving

A3 problem solving report is a visual, A3 size template for systematic problem solving. It establishes a basic outline for user to successful resolution. It is used for solving everyday issues in our daily work life. (Sobek & Jimmerson 2006)

The outline is as follows:

1. **Issue statement:** a descriptive title for the report.

2. **Background to the problem:** relevant information to connect the issue with the broader organizational and historical context. Identify the problem.

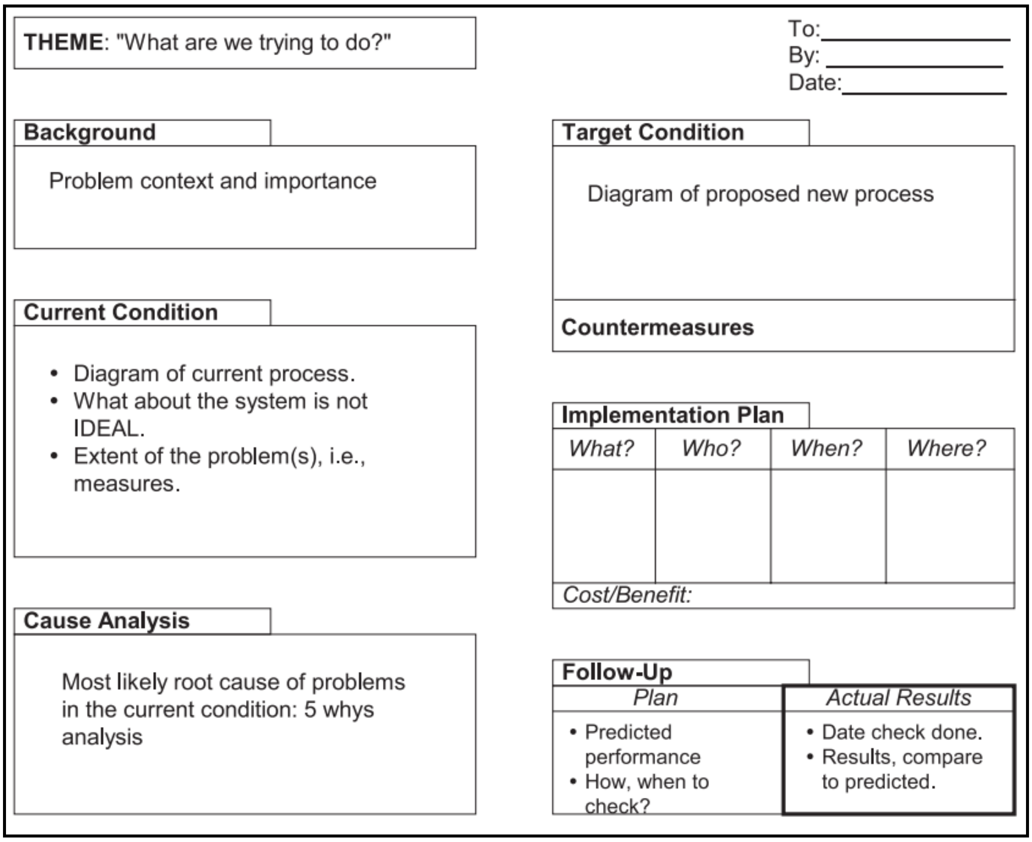
3. **Current Condition:** an iconic diagram that describes how the process currently works, with the main problem labeled and data describing the extent of the problem. If possible, go and see problem process first hand.

4. **Cause Analysis:** chain of cause-and-effects leading to the root of the problem. '5 x why´ root cause analysis may be applied. The apparent direct cause is rarely the root cause.

5. **Target Condition:** proposed countermeasure(s) to the root cause(s), an iconic diagram that describes how the new process will work with the proposed countermeasure(s) implemented, and predicted performance.

6. **Implementation plan:** the actions required to realize the target condition, who will take each action, and when.
7. **Follow-up plan:** how and when the user will verify that the target condition was realized and that the predicted results were achieved. Obtain approval from appropriate authority.

8. **Results**: the actual results of implementation.



Picture 5 Example of A3 template (Jimmerson et al 2005)

This kind of systematic way of problem solving makes sure that all steps required for solution are taken. It is important to facilitate the schedule and the persons responsible for the actions to achieve things done. The heart of this system is to truly analyze the root cause instead of the symptoms. (Sobek & Jimmerson 2006)

'5 x Why' Root Cause Analysis

'5 x why' is a part of Toyota Production System. Toyotas famous engineer Taiichi Ohno developed this simple system. When production faced problems, people tended to blame each other for them. His favorite tool for solving these problems was 5whys analysis. (Benjamin & Muthaiyah 2010)

Here is Ohnos infamous example of the use of 5whys:

Question 1: Why did the robot stop?

Answer: The circuit is overloaded, causing a fuse to blow.

Question 2: Why is the circuit overloaded?

Answer: There was insufficient lubrication on the bearings, so they locked up.

Question 3: Why was there insufficient lubrication on the bearings?

Answer: The oil pump on the robot is not circulating sufficient oil.

Question 4: Why is the pump not circulating sufficient oil?

Answer: The pump intake is clogged with metal shavings.

Question 5: Why is the intake clogged with metal shavings?

Answer: Because there is no filter on the pump.

This zero cost analysis can bring easy way of finding the root of problems rather than the symptoms. (Benjamin & Muthaiyah 2010)

Integrated design and construction + lean practices

Implementing lean to a construction design process does not come without difficulties. To tackle these difficulties Jorgensen and Emmitt (2009) in their paper list following issues to be important in achieving good results:

- Value specification
- Active client, user and stakeholder involvement
- Decision and decision process transparency
- Transparency regarding value and waste consequences of design decisions
- Management of design iteration processes
- Collaborative design with contractor and supplier involvement
- Commitment from project participants (including suppliers)
- Project team learning

2.3 Co-operation management methods

In this chapter four methods for collaborating working and their design management are introduced. These methods were selected under revision because they are known to be used and tested in the construction industry.

2.3.1 Concurrent engineering

Concurrent engineering is production management philosophy that arises from the manufacturing industry. Because of achieving faster product development times there, it has raised interest also in the AEC industry. The key idea behind concurrent engineering is to use overlapping processes and shortening completion times instead of using sequential processes. (Bogus et al 2005)

So the number one feature in concurrent engineering is shortening of design schedule. This chapter revises what are the key factors for one to be able to shorten design time. This means understanding the nature of tasks at hand and the information flows between tasks. Understanding these requires understanding of task related concepts: dependencies, evolution, sensitivity, rework probability, upstream and downstream information.

Starting and completing a task requires certain information. Weather the source of information is from completing or partly completing another task determines the **dependency** between these two tasks. If a **downstream activity** requires information from **upstream activity,** they can be called **dependent**. Tasks can be categorized to four dependency classes depending on the required information exchange between them. This determines how they can be overlapped. Categories are dependent activities, semi-independent activities, independent activities and interdependent activities. (Bogus et al 2005)

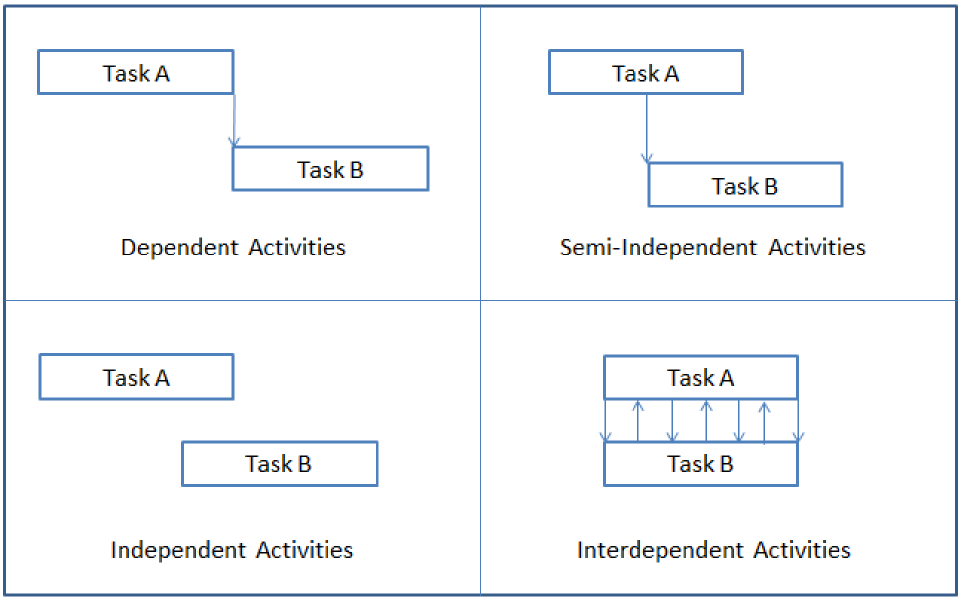


Figure 13 Four types of activity relationships (Prasad 1997)

Independent activities are the only ones that can be overlapped without a risk. Overlapping dependent activities increase risk of delay. Preliminary information exchange between tasks in the beginning of tasks can reduce the risk. (Bogus et al 2005)

When overlapping tasks, the sensitivity between them must also be taken into consideration. **Sensitivity** is a concept which determines how changes in information affect the tasks. The amount of rework needed is the measure for sensitivity. (Bogus et al 2005)

Example: A and B are overlapped. B receives information from task A. This affects the B and changes and rework is required. In this case A and B had sensitivity between them.

Evolution describes the rate at which design information is generated from the start of an activity through the completion of the activity. (Bogus et al 2005)

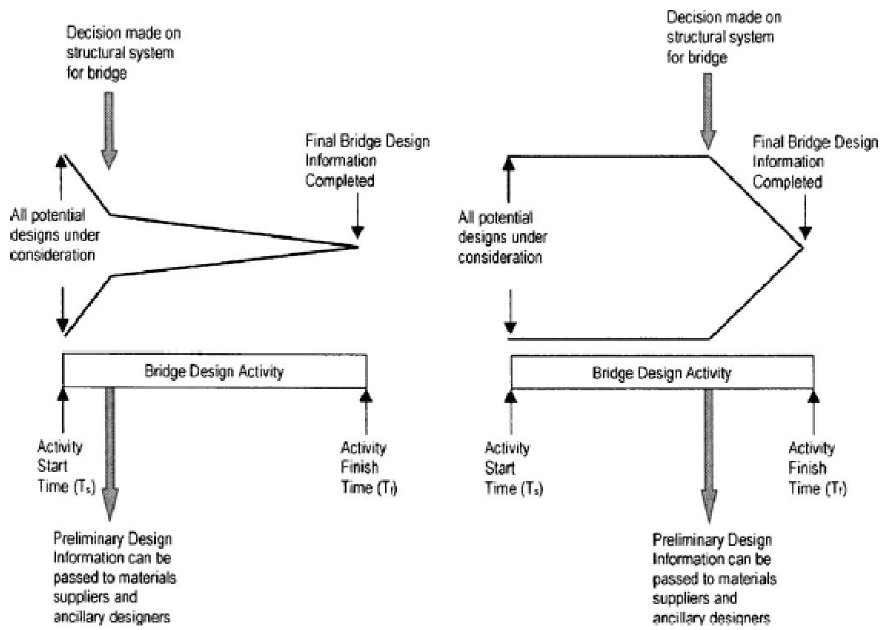


Figure 14 Fast and slow evolution (Bogus et al 2005)

Evolution and sensitivity characteristics of tasks are used to identify overlapping possibilities. Optimum conditions for overlapping are achieved when dependent tasks have a low sensitivity and a fast evolution. (Bogus et al 2005)

In their paper Bogus et al. (2006) introduce strategies for overlapping design activities. Strategies vary by the cholesterics shown above. Using these strategies project managers can reduce overall project delivery time. These strategies either speed up the evolution of a task or reduce the sensitivity.

Strategies for speeding up evolution:

Early freezing of design criteria

Early freezing of design criteria allows early release of information for downstream tasks. Strategy requires early commitment for the design criteria. This reduces uncertainty of information to downstream activities. Freezing strategy might lead to a situation where the design solution is not optimized. Worst case scenario is that selected criteria cannot be established and amount of rework increases.

Early release of preliminary information

Early release of preliminary information from upstream activity allows the downstream activity to start before upstream task is complete. Too early release increases the risk of changes in the preliminary information which can lead to increased amount of rework.

Prototyping

In prototyping a working model of current best knowledge is gathered to be presented for downstream activities. This promotes communication among project designers. Prototyping can be used with complex systems and when there are many pieces of information to be relied to downstream activities. Prototyping allows the downstream activity to begin when the model is complete, but when the design is not complete and accurate.

No iteration No optimization

In a slow evolving activity limiting iteration and optimization speeds up the evolution. There can be set time limitations or a limitation for number of iterations. When time is up or the times of iteration are used the best solution achieved by then is used for further development. This strategy is basically just setting time limits for design. It includes the same risk as early freezing of design criteria which is that non optimized solution might add costs further in the project. Over optimization on the other hand might also lead to increased cost. For example if designer over optimizes rebar amounts, it might lead to more complex system that increases overall costs.

Standardization

Using standardized products, components and design solutions speeds up the evolution of an upstream activity and allows faster information exchange to downstream. Solutions should the kinds which are used repetitively in projects. Risk lays in non-optimizing the design solution. Strategy also includes a positive risk of decreasing costs. Standardization may eliminate sub-optimal solutions and increase the contractibility of the design.

Strategies for decreasing sensitivity:

Overdesign

In overdesign strategy designers make rough, conservative estimates that allow the downstream activities begin before the upstream activity is complete or even begun. Conservative estimates are given on size or strength of project components.

Set-based design

Set-based design is a design strategy to decrease the sensitivity of downstream information. In this strategy a set of design solutions are developed simultaneously. As design progresses the optimum solution is narrowed down. To reduce rework the design team must commit to the first set of solutions. Consequence of this strategy is increased design costs if compared to developing a single conservative solution.

Decomposition

In decomposition strategy the upstream activity is divided to smaller packages. This might create faster evolution. Decomposition should be used when other strategies cannot be applied. Objective of the strategy is to create new activities that can be re-evaluated and overlapped using other preciously mentioned strategies.

These strategies can be used to reduce delivery times. Combining different strategies is also possible. To reduce risk of rework strategies should be applied activities with matching characteristics. In figure below strategies are put to framework of their usability in different activity characteristics.

Sensitivity / Evolution	Slow	Fast
Low	Overdesign Early release of prelim info Prototyping No iteration/optimization Standardization Set-based design	Overdesign Early freezing of design Early release of prelim info Prototyping
High	Overdesign No iteration/optimization Standardization Set-based design Decomposition	Overdesign Early freezing of design

Figure 15 *Use of overlapping strategies with different activity characteristics (Bogus et al. 2006)*

2.3.2 Project Alliancing

This chapter gives a general description of what is usually meant by project alliancing (PA). PAs history starts from the beginning of 1990s oil industry projects in UK. After achieving good results there it was then used for the same purpose in Australia. First construction project delivered with PA was in 1997.(Lahdenperä 2009.) From there it has spread around the world.

PA has established a stable position as form of project delivery in construction projects around the world, including Finland. Alliance is usually modified to match the application country's legislation on public procurement. This is why alliances might differ country by country. This is why in this thesis the general essentials and principles are researched.

Definitions for project alliance:

1. "A project alliance is where an owner (or owners) and one or more service providers (designer, constructor, supplier, etc.) work as an integrated team to deliver a specific project under a contractual framework where their commercial interests are aligned with actual project outcomes." (Ross 2003)

2. "Project alliance is a project delivery method based on a joint contract between the key actors to a project whereby the parties assume joint responsibility for the design and construction of the project to be implemented through a joint organization, and where the actors share both positive and negative risks related to the project and observe the principles of information accessibility in pursuing close cooperation." (Lahdenperä 2009)

Essential part and the key idea of project alliancing is risk and reward sharing among participants. They share the risk management and outcomes of the project together. This provides the foundation for alliancing and to which all other characteristics pin to: collaboration, making best-for-project decisions and innovation. Goal of these essentials is to achieve value for money to the owner. (National Guide to Alliancing 2015)

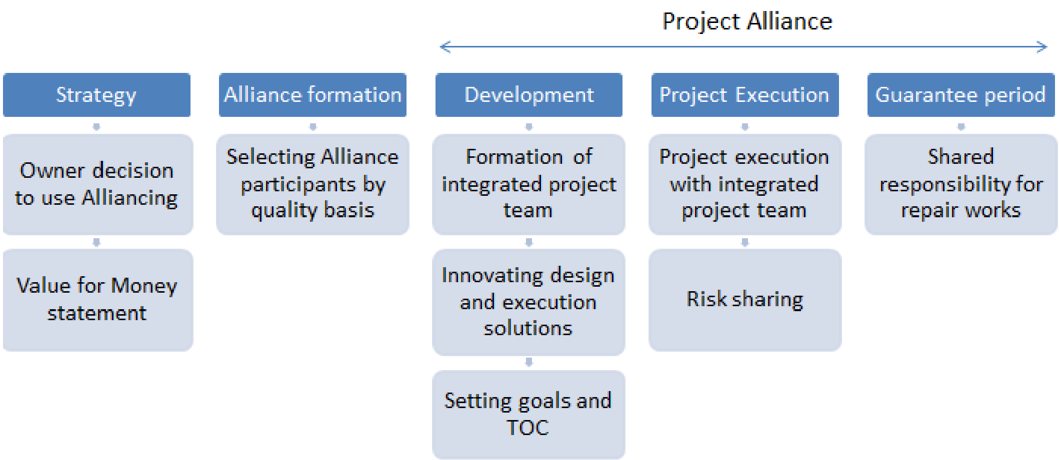


Figure 16 Phases of project alliance (Pellinen 2012)

Success factors for Alliancing are according to the Australian National Guide to Alliancing (2015):

Integrated, Collaborative Team
Team includes members from owner and non-owner side of the project personnel. The team works under the alliance values and established project culture.

Project Solution
Project solution includes the design, construction methods and project delivery arrangements.

Commercial Arrangements / Commercial Framework
The arrangement reflects the project solution. Risk and reward sharing directs the project participant behavior to desired direction to achieve the project goals.

Target Outrun Cost (TOC)
TOC is the estimated actual costs of all assets in the project. It reflects the project solution and commercial arrangements.

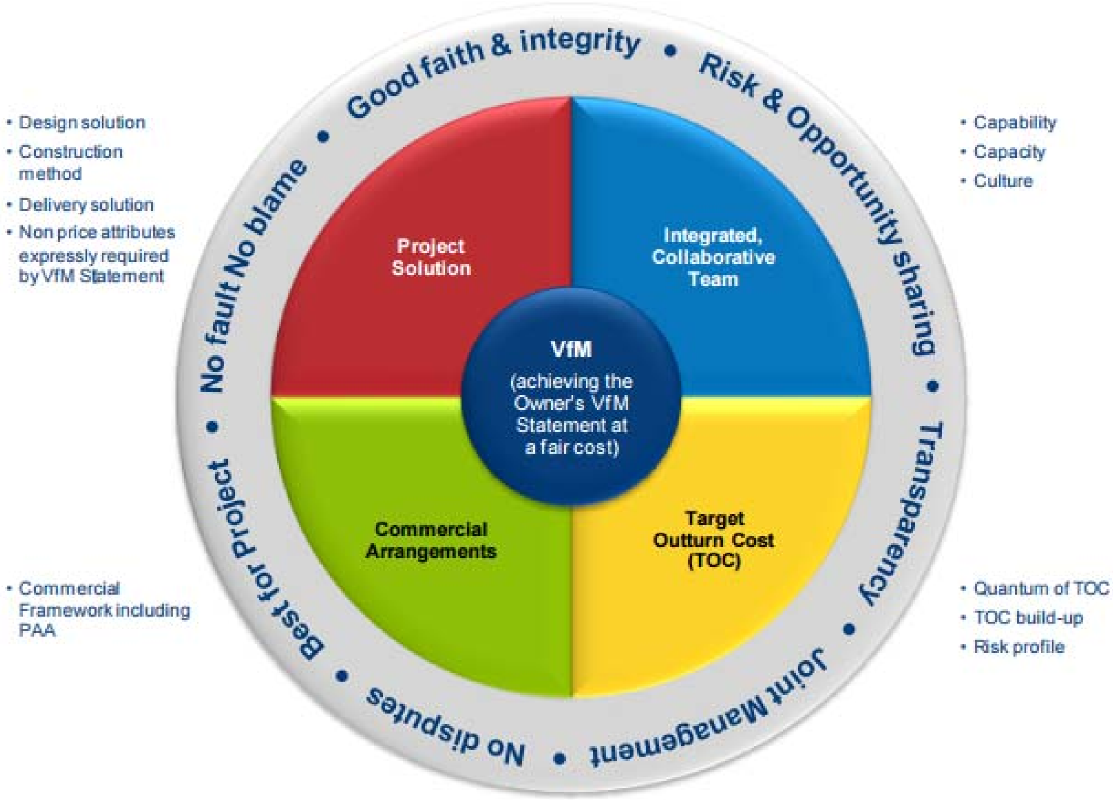


Figure 8 Alliance success dynamics (National Guide to Alliancing 2015)

Key features/values of Alliancing are (National Guideline to Alliancing 2015) also called as the soft elements of alliance (Lahdenperä 2009):

Risk and Opportunity Sharing
Encourages effective collaboration. Owners may hold on to some risks to gain maximum value for money. Traditionally the risks of the construction phase have been 100 % allocated to contractor. Now owner and the designers also share the risk of construction phase and vice versa to the development phase.

Commitment to 'no disputes'
This is a mechanism that prevents quarrelling and juxtaposition in projects. Disagreements of course arise inside the project but they are solved in the projects own disagreement mechanism rather than in court.

Best-for-project decision making
This kind of method is applied because in some cases the participant's self-interests might collide with the projects benefits. In alliance this is avoided by tiding the participants together by rewarding them by the success of the project. In case of alliance owner trades-off some of the traditional decision making rights for the collaborative decision making.

No fault-No blame culture
Rather than blaming for failure or poor performance the project team focuses on solving the problem and its consequences.

Goof faith and integrity
The requirement to act in good faith is generally limited to the performance of the collective obligations and responsibilities of the alliance. It is nevertheless a vital element to achieve concurrent risk sharing.

Transparency
Open book arrangement makes it possible for all participants to actually see all the costs in the project. It is required to maintain integrity in the project.

Joint Management/Alliance organization
Descriptions referred from National Alliance Guidelines (2015) and supplemented with more accurate descriptions when needed from Lahdenperä (2009).

The organization in alliance comprises of both owner and non-owner personnel (NOP).

Figure 18 Alliance organization (Lahdenperä 2009 and National Alliance Guidelines 2015)

Alliance Leadership Team (ALT)

All the participants provide their best resources for the ALT. Members must have decision making capability inside their own organizations.

Responsibilities:

- Creates team spirit and operational vision and maintains them
- Creates principles of organization and sets goals for project organization
- Approves alliance and operational and cost goals Evaluates and accepts alliances action plan and procedures
- Appoints and authorizes alliances project manager
- Appoints and accepts members of PMG
- Assists in the maintenance of interest group relationships
- Seeks out best resources of participating organizations
- Monitors outcome and corrects direction as necessary Defines and solves differences in views between participants

Alliance Manager (AM)

This person is selected by the ALT to lead the alliance. The AM reports to the ALT and is responsible for the delivery of the project. Typically this person is a highly experienced project manager from a NOP and chairs the AMT. AM is the chairs the project management team.

Project Management Team

Project management team comprises of at least one member of each contracting partner. They are full time participants in the project. Members of the team can change according the needs of the project at each phase. Goal for the group is to make unanimous decisions. If not achieved alliance manager uses his authority to push the project forward without consensus.

Responsibilities:

- Responsible for delivery of agreed structure/system
- Approves and authorizes rest of project organization
- Manages project implementation on operative level
- Provides effective (work) supervision for rest of project organization
- Monitors, forecasts and reports on implementation to ALT
- Undertakes necessary corrective measures

Project Organization

The task of project organization is to execute the project. Double roles are not allowed. Each member has a clear responsibility for certain project section and tasks.

Responsibilities:

- Responsible for practical implementation and achieving of result
- Has a clear scope of liability by actors with respect to outcome
- Made up of actors appointed with interest of project in mind
- Operates as a united team forgetting the views of the background organizations

This is the typical Alliancing organization. In addition to that, there might be a need for **sub consultants**. If the project realizes the need for some extra experience that cannot be found inside the project personnel, other consultants are hired to support the project.

Organization is an important factor for alliance to succeed. But what really ties the participants together is the commercial model of alliance.

With the **commercial model of alliance (**also called alliance compensation model) the participants are tied together to achieve common goals. Basic idea is that based on the open book principle where everyone wins or everyone loses based on the success of the project. The main part of this model is the Target Outrun Cost (TOC). (Lahdenperä 2009, National Alliance Guidelines 2015, Love et al 2010)

Target Outrun Cost is result of project design and the estimated costs that have been counted with the transparency principle. TOC consists of **estimated project costs, corporate overhead costs, marginal profit of participants and project-specific overhead costs**. TOC is formed in collaboration and alliance participants are committed in reaching it. Their profits from the project are tied in achieving it. Other meters for the success of the project can be included in the commercial model. This kind of profit tiding **Key Result Areas (KRA)** could be safety, schedule or environmental issues. (Love et al 2010)

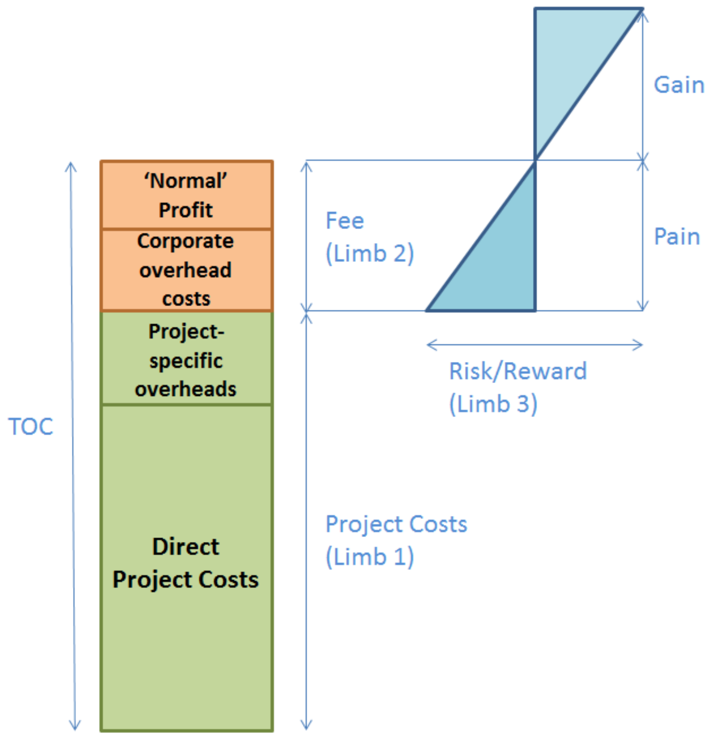


Figure 9 Alliance Commercial Model (Love et al 2010)

Alliance commercial model is formed of three limbs: project costs, fee and risk/reward performance incentive payment. (Love et al 2010)

Project costs

In alliance the owner commits in compensating all direct project costs that fall on NOPs. This is the risk of the owner and this is why the alliance must be based on mutual trust.

Fee

In alliance project NOPs are responsible for the success of the project with their fee. In short if the project fails, no profit is made by the participants. The fee is compensated if the project results in 'normal performance'.

Risk/Reward

NOPs receive a penalty or bonus based on the performance in non-cost related measures. This part of the model varies project by project.

2.3.3 Integrated Project Delivery

Integrated Project Delivery (IPD) is a new kind of contracting form for construction projects. IPD is used to describe significantly different contracting forms. This is why IPD lacks a uniform definition in the construction industry. Although there can be found uniform characteristics of it in many sources. (Kent and Beckerick-Gerber 2010). These characteristics are researched in this chapter. Integrated Project Delivery hasn't been found possible to be applied as it is to Finland by local construction industry. This is why in this chapter I will concentrate on the key principles and catalysts for IPD that still could be beneficial for developing the current design management processes. Nevertheless, Integrated Project Delivery: A Guide (AIA 2007) defines IPD as follows:

"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction."

IPD tries to solve a problem of a construction industry. The problem of traditional processes has been that the self-interest of project participants clashes with the projects goals and lacks innovation. This might also lead to rise in costs and time consumption. IPD tackles the problem by introducing a model of mutual responsibility. (Thomsen et al 2009) Realization of IPD is that effort in design phase will result in cost and time savings in the execution phase. (AIA 2007)

The guide (AIA 2007) claims that the IPD principles are compatible with every form of project delivery.

In the heart of IPD are new kind of contracts that bond all project members to mutual goals and their success. In a nutshell, if the project fails, all participants lose money and if the project succeeds, everyone wins. (AIA 2007). With other words project members share the risks of the project with the owner or client. (Zhang and Li 2014) This is achieved through open environment of information sharing in the project. (AIA 2007)

For IPD to be successful all the parties must follow the following key principles (AIA 2007):

Mutual respect and trust

Understanding the importance of collaboration and committing to work as team in the best interest of the project.

Mutual benefit and reward

Incentives in the project are tied to achieving project goals.

Collaborative innovation and decision making

Free exchange of ideas stimulates innovation. Key decisions are evaluated by the project team.

Early involvement of key participants

Key participants are involved in the project as early as practical. Having the best knowledge at the beginning of the project is beneficial. At the early stage of the project the decisions made have the most impact. The new idea here is for contractor to also contribute to the design in larger scale.

Early goal definition

Project goals are developed early, agreed upon and respected by all participants.

Intensified planning

IPD approach recognizes that effort put to planning will increase efficiency and result in cost savings in execution phase.

Open communication

Team performance is based on honest and open communication. Responsibilities are clearly defined and culture of problem solving is established instead of blaming culture. Disagreements are perceived and solved as they occur.

Appropriate technology

Cutting edge technology is used to support the goals of the project. Open and transparent data structures with the technology supporting it are essential.

Organization and leadership

Roles are clearly defined project-by-project bases. Leadership is taken by the team member with most competence regard to specific work and services. Competence is supported by the knowledge of the whole project team.

IPD mimics and has its roots in project alliancing as it can be seen from the key principles of IPD presented above. IPD also uses similar idea of risk/reward shearing between participants. (Lahdenperä 2012 and Zhang & Li 2014) IPD in addition emphasizes the early involvement of designer and contractor. IPD takes contractor involvement further than Alliancing. In IPD all sub consultants and subcontractors are counted as key participants who are involved in the process of developing the project as well as managing it. This depends on the project needs. (Aschraft 2011)

Being developed at 21st century IPD also emphasizes some newer characteristics compared to Alliancing. These include co-location and BIM. (Aschraft 2011).

Kenig et al. (2011) call these newer characteristics as catalysts for IPD. They include in these catalysts: multi-party agreement, building information modeling, lean design & construction and co-location of the team. Below is explained how these work as a catalyst.

Multi-Party Agreement

Including all the key project participants under one contract, same set of rules and behavior supports IPD projects.

BIM and IPD

Collaborative decision making is fundamental for IPD. BIM supports this and also in other means of collaborative project delivery. The key is the integration of information that BIM makes possible. BIM also adds value for owner in the facility management phase. Previously owners might have faced information loss at the end of construction phase. BIM can work as a way to conserve this required information for facility management.

The key for successful BIM implementation in IPD is to use one shared BIM instead of several separate ones.

Lean

IPD and lean both strive for the same outcome of adding more value for owner. Early adaptation of both principles will lead to more successful outcomes.

Co-location

The basic idea of co-location is that it raises the amount of communication between project participants. This leads to better ideas, solutions and innovations. Co-location office encourages members to face-to-face communication. (Thompson & Ozbek 2012)

Co-location rises to its full potential in large projects. Smaller projects can benefit from shorter periods of co-location, say 2-3 days a week. (Thompson & Ozbek 2012)

In co-location office each cluster is producing visual material on their schedule, costs and BIM for other to be observed. (Thompson & Ozbek 2012)

Not all members of the project needs to be situated at the co-location office. The key personnel, people working full time for the project and at least one representative of each participating company should be present. (Thompson & Ozbek 2012)

Co-location removes the constraints of the different company cultures in a project and lets the project to develop a new culture of working – best for project. Co-location participants also increase their knowledge on the design work of other principles. A good way of yet increasing the amount of braking barriers between designers is to relocate the designers inside the office on frequent periods. This method forces the office members to interact with new project team members. (Thompson & Ozbek 2012)

Co-location makes the information exchanges easier. In this environment it is always possible for someone to question anyone. This possibility cuts the middleman that used to be the representative in design meetings for that specific discipline. The one that requires some information say for a design solution can ask that question frequently from the person with the best knowledge on the matter. (Thompson & Ozbek 2012)

2.3.4 Knotworking

Integrated project delivery and Big Room collaboration have been methods that have been developed along with introduction of BIM to ensure collaboration inside construction project. They apply well to large scale projects where the whole resources of a design team can be directed to a single project. The implementation of these methods to Finnish projects is challenging due to small project size. Because of this, knotworking has been developed to deal with the collaboration issues. (Kerosuo et al. 2013). *Knotworking can also be called as agile co-working sprint*. (Lavikka et al. 2013) *This chapter revises research papers covering the subject and represent the process.*

The concept of knotworking was created in the research and development of health care conducted in the Center for Research on Activity, Development and Learning (CRADLE) at the University of Helsinki. After its initiation it has been adopted to various projects internationally in educational and social sciences. (Kerosuo et al. 2013).

Kerosuo in her paper BIM-based collaboration across organizational and disciplinary boundaries through knotworking (2015) defines knotworking as follows: "Knotworking is introduced as a new idea and an emerging practice for enhancing collaboration across organizational and team boundaries in BIM-based building projects. Knotworking refers to co-located 'knots' that are organized on a temporary basis to solve a specific task, a problem or an open question requiring multi-disciplinary expertise in a building project."

Another definition in a paper Knotworking - A novel BIM-based collaboration practice in building design projects (Kerosuo et al. 2013) defines knotworking as follows: "Knotworking represents a distributed collaborative expertise in pursuit of a task that is organized among designers from different design disciplines. Construction processes involve phases and tasks that cannot be solved in one organization only, as integration of expert knowledge from various sources is needed. Through knotworking, groups of people, tasks and tools are set to work intensively for a short period of time to solve a problem or accomplish a task."

Basic characteristics of knotworking are identifying a knot in the process and gathering the right people to solve it. Task usually requires problem solving and expertise of different disciplines. Solution might be complex. It is not a same thing as having a meeting. (Kerosuo et al. 2013) In comparison to normal meetings knotworking sessions unclear issues are not left to solve between meetings, but rather in the session. (Korpela 2015)

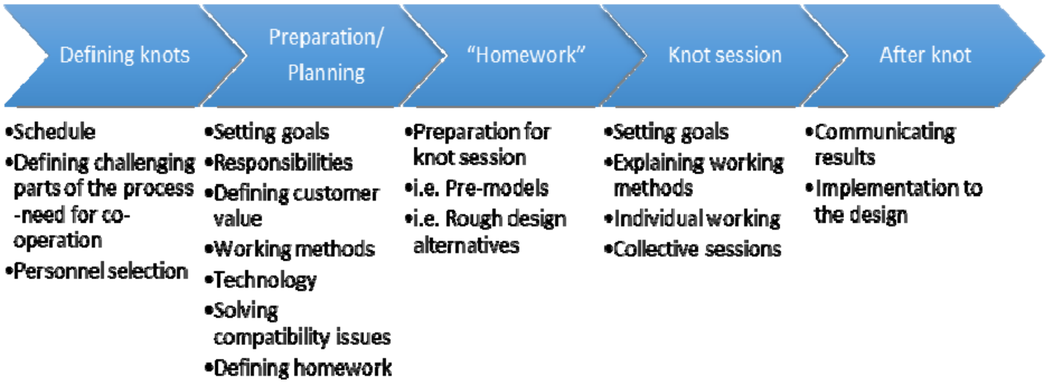


Figure 20 *Knotworking process*

The planning of knotworking starts from defining the phases of the project where knotworking is needed. In the planning it should also be selected the personnel with the expertise and capability of decision making to solve the occurred challenges. These participants should also have problem solving ability and openness to other's ideas. (Korpela 2015). Kerosuo et al. (2013) also suggest based on their research that client immobility should be required in knotworking sessions. This eases the decision making in the sessions.

Preparing the agile co-working sprint must be done carefully to achieve good results. In preparation sessions the goals of the knot must be defined. Other issues to be prepared are added customer value, working methods and an action plan supporting of achieving the goals and added customer value. In addition to these, also practical issues should be discussed. These include the compatibility issues of different design software and supplies of other technology that supports the co-operation. In the preparation meetings the homework for participants should also be decided. (Lavikka et al. 2013, Kerosuo 2015)

The actual knotworking sessions are then executed according to the action-plan. The sessions, researched in the papers Lavikka et al. (2013) and Kerosuo (2015), started with info section. In this part the participants were to motivate, inform of goals and share the action plan. The agile co-working sessions were then divided to co-working and individual work sessions. During co-working the new produced information were shared and discussed.

After the knotworking session has come to conclusion and achieved the results it is important to communicate the results. Results should be communicated to all the project personnel. Further implementation of results to the design must be applied if they have not been applied already at the session. (Lavikka et al. 2013)

Outcomes of using knotworking are described in the research papers mentioned before in this chapter. Knotworking increased the understanding of each other's work between participants. The speed of information exchange was raised due to co-location. Participants found an advantage in commitment to the goals that were set together. They also believed that the designers are more committed to the design solutions made during the session. The visual results achieved were found to be beneficial for customer decision making. (Lavikka et al. 2013)

In the paper of Korpela (2015) the view point of client was researched. The research noted that knotworking was beneficial in transforming the needs of client to the design team. During the knot the designers could ask clarifying questions from the client as work progressed. Client also became more aware of client's own needs during the process. In total knotworking worked well as a collaboration method in papers case project. Using the expertise of all parties to improve the design solution was achieved.

All the research papers investigated in this thesis agreed on that knotworking works as a good new BIM collaboration method.

2.4 Summary of theory research

This second part of the thesis covered the subjects related to developing design management from different approaches. The different subjects covered the development of design management from detail level of BIM format issues to whole philosophy of process improvement.

Following text is meant to summarize how these researched methods can be applied to improve design management in projects. Summary also covers the key points of each subject. The figures give insight on how these different subjects relate to the construction process.

The researched guidelines gave a lot of hands on, practical suggestions and requirements for BIM design management. Following the guidelines in a project, makes BIM design possible. They can be considered as a minimum level of management needed in a project. Guidelines varied a lot on the level of detail. Their appliance to infrastructure engineering was found to be poor in some cases as they focus more on housing engineering. The guidelines for collaboration and information exchange on the other hand apply to both.

Following picture describes how the different guidelines differ in their coverage in relation to the whole construction process. Contents of the guidelines differ from covering the whole BIM process of the project to detailed level of matters in small parts of the process. The guidelines that cover the whole construction process might not go into as much of a detail as the guidelines that cover just a certain part of the process. For example general guideline as Singapore BIM Guideline tries to cover the whole process where PAS and BS standards only cover a specific area of the process.

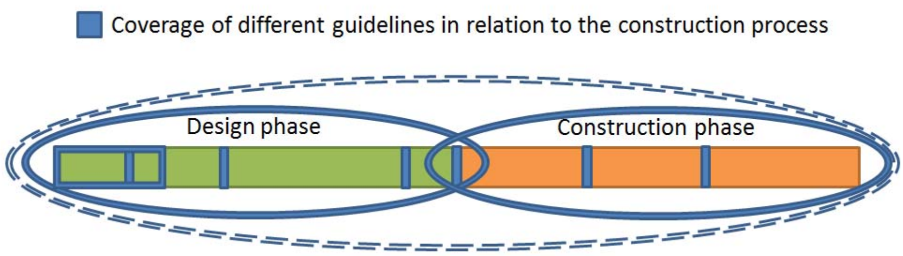


Figure 10 Guideline coverage in relation to the construction process

The figure shows that not a single guideline can be used to fully manage the BIM process. Understanding of the process is needed in the detail level and this requires referring to specific guidelines.

Alliance and IPD project deliveries approach was different from BIM guidelines. The key elements of these methods were the contractual/financial tiding and early involvement of key parties in the project. Having all the possible expertise at the beginning of the project, where the decisions with largest effects, sound like a great idea. In according to these elements one of the key element for these methods were the best for the project ideology. Contractual tiding forces the parties to work for the project rather than their self-interests.

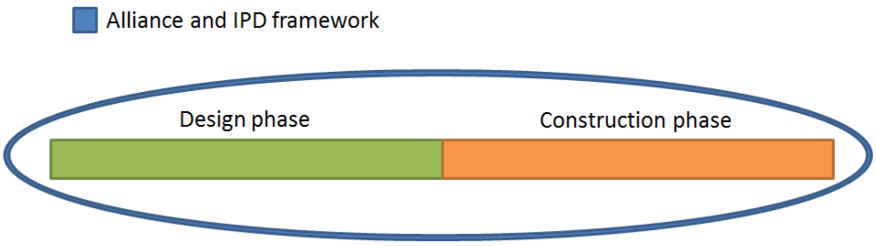


Figure 22 *Alliance and IPD are project delivery methods for the whole construction project*

Knotworking was a method that can be applied to certain problem or design phase where intense information exchange is needed. Because of this it can be applied to be a part of any design process. Following picture helps to

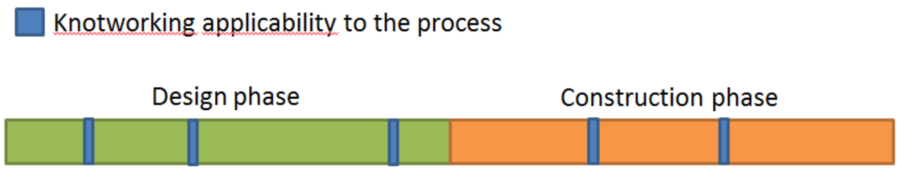


Figure 23 *Knotworking can be applied to certain identified, critical parts of the process*

Lean on the other hand can be described as a philosophy of constant development. When lean is seen this way, it can't be considered as a project based design management. The framework of lean covers everything done in one's business. Of course methods and techniques from TPS have been applied to develop processes in construction industry as well. This was defined as Lean construction. Applying these TPS techniques might be a good starting point for one to start managing development.

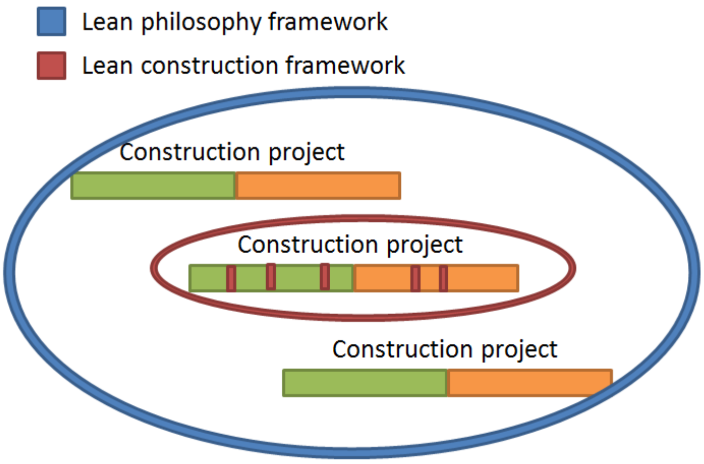


Figure 24 Lean philosophy and lean construction framework

3 Research methods

Research methods in this thesis consist of four different methods. They include interviews of project personnel, design management and BIM process literature research, the case project's meeting analytics and common data area analytics. These methods were selected to support the goal of the thesis and to find answers to research questions.

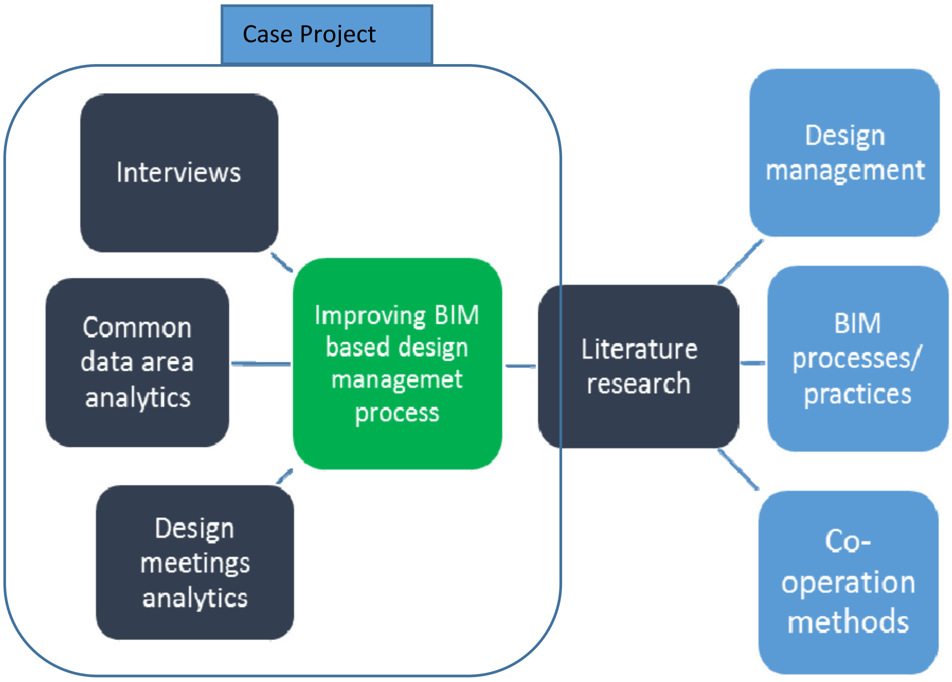


Figure 11 Research methods

Research in this thesis was done based on the case project. The case project provided a fruitful opportunity to research the BIM based processes in action. This provided more realistic view and data to support research. In the case project design was done in three separate design groups. These groups had a different approach in the design processes and the use of BIM.

Wide use of BIM was required by the client in the project. It was interesting opportunity to see the difficulties and opportunities that this decision results. Especially the solutions to these problems are interesting and beneficial in the view point of future projects. In the case project the thesis was able to access all the project data and documents.

The timing of the research in the project was in the end of preliminary phase of the design process. Following the meetings and interviews were done just before the deadline for returning the preliminary drawings and models for the client.

3.1 Interviews

Interviews were selected as a research method to gather opinions of BIM design management issues from the experts of the field. The interviewed people were the key personnel working with modelling in the case project. These people hold the key knowledge of improving the process because they are involved in the project and modelling daily in their work. Selected interviewees have years of experience in construction projects and in construction design.

In this thesis there were 12 interviews conducted altogether. They were selected from different design disciplines to raise understanding on the overall picture and the way of modelling in different disciplines. This was also hoped to give solutions in ways of co-operation between different design fields and project parties.

Table 6 List of interviewed case project personnel

1.	Architecture BIM cordinator
2.	Structural engineering BIM coordinator
3.	HVAC BIM coordinators
4.	Structural design BIM coordinator
5.	Electrical engineering BIM coordinator
6.	Railroad engineering(2 persons)
7.	Rock engineering BIM coordinator
8.	Architecture BIM coordinator
9.	Architecture BIM coordinator
10.	Project coordinator, City of Helsinki
11.	Project manager of the project bank/cloud service provider
12.	Geotechnical engineer
13.	Structural engineer

Interviews have these seven goals:

- What is interviewees role in the project
- How different disciplines use BIM
- What are the technical difficulties in the use of BIM
- How their work is related to work of others
- What are the main dependencies between disciplines
- What was well executed in the case project
- What improvements should be done in future projects

3.2 Co-operation analytics

Co-operation in the case project is analyzed by following the project's meetings.

Project meetings are the forum for co-operation between different design disciplines. This is why they were selected as a part of research methods in this thesis. Following the meetings also provided good overall view of the project at the beginning. This helped to start the research and select the people to be interviewed.

In this thesis there were few different types of meetings that were followed:

- Meetings to combine produced models
- Design groups weekly design meetings
- Design meeting with designers and clients
- BIM usage development team meetings
- Clients BIM development group meetings

The goal of following projects was to understand the design process in the case project. Also the use of the BIM was followed in the meetings. Different roles in the meetings were tracked and the process of problem solving.

3.3 Analytics

Analytics were selected on the basis of available data. From the available data it was then selected which would support the goals of the thesis.

During the theory research there were papers found researching the dependencies in the design processes (Senescu et al. 2012). It was decided with the instructors to use the available common data area log data to map these dependencies in this case project. The goal was to use design structure matrix techniques to improve the existing process.

4 Data collection and analytics

These following analytics have been a result of thinking process:
- Which data is easily accessible?
- Which data is analyzable?
- Which data is valid?
- Recommendations from instructor

4.1 Interviews

In interviews it was 12 interviews conducted to 14 people. The interviewees were the BIM coordinators of the City Rail Loop case project and other personnel working with modelling in the case project.

Interview questions were prepared before interviews to support the goals of the thesis and to get an overall picture of the project modelling process. Questions were the framework for the interviews but discussions in the interview situations might have expanded to cover also other subjects. After two first interviews the questions were modified to cover the important subjects related to the thesis. These new questions were raised in the first two interviews. The questions were as follows:

- What is your role and responsibility in this project?
- How does your design principle use modelling as a tool?
- What has been the BIM process in your design discipline?
- What kind of roles does this BIM process include?
- What is the process to produce compatible models?
- What problems or difficulties has the BIM process had?
- How could the BIM design process be improved?
- What kind of references is needed for your discipline from other disciplines?
- What reference information is needed by other disciplines from your discipline?
- What is the process in the situation of design changes?
- In what kind of accuracy should modelling be done in each phase of the project?

To the interviewees that were not BIM coordinators or designers the set of questions were different. They were asked about the processes of the project and their use of the BIM.

4.1.1 Results of the interviews

The results of the interviews are here collected together from different interviews under specific topics.

First part handles the status of how the designers in different disciplines use BIM and how disciplines are related to each other in the design process. The first topics that describe the use of BIM and the need for information by discipline are:
- Use of BIM as a tool by discipline
- Role of the BIM coordinator by discipline
- Main needs of information by discipline

The second part describes learnings in the use of BIM in the case project. The following topics describe the interviewees' opinions on the design and modeling processes and development suggestions for future:

- Modeling accuracy
- Good practices, BIM benefits and good co-operation methods
- Development suggestions

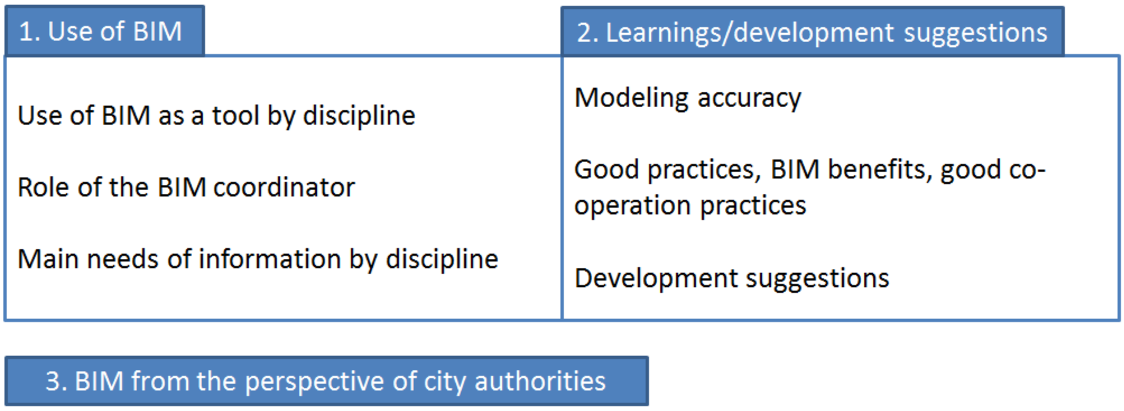
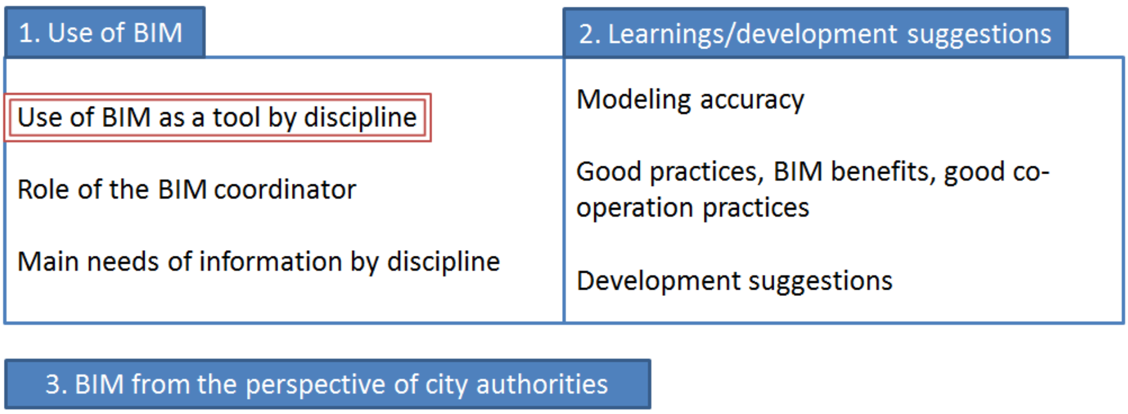


Figure 12 Structure of the interview results

The last part of this section describes the results of interviewing the project coordinator of the city side. In this interview he was asked about his opinions on BIM and the needs of modeling from the perspective of the Helsinki city. This part is called **BIM from the perspective of city authorities.**

Use of BIM as a tool by discipline



The interviewees were asked how their design discipline uses BIM as a design tool. The answers varied. This was also found to be one of the problems in BIM based projects. Below are the answers given by specific disciplines:

Structural engineering

1. BIM and especially Tekla Structures has been the main design tool for a long time already. Engineers produce the model as the design works progresses. Models from other disciplines are used as a reference.

2. Due to changes in the design solutions the modelling hasn't been as optimal as it should. Sometimes it has been done backwards: first design with CAD tools and then modelling. The order should be that first modelling and then the drawings from the model. Models have been the main source of referencing the work of other disciplines. At this preliminary phase of the project the model accuracy has been kept at a low level. This means that the geometry and the need for space have been the main requirements for the model.

Electrical engineering

Electrical engineering uses Navisworks as their modelling tool. The design is done straight to model as it is faster for the designer.

HPAC engineering

HPAC engineering does their design work in the modeling environment. Comment given by the interviewee considering the benefits of BIM was: "How a project this complex has before been able to design without modeling."

Geotechnical engineering

First the reference models are produced from the existing structures and foundations underground in the area of the station. In the beginning of this project the drawings were mainly produced from CAD software. Lot of drawings were required from the side of developer. But now at the end of preliminary phase of design the design work can be done completely based on modelling. This is because now all the models of the disciplines are in the accuracy that makes co-operation possible. References from other disciplines are models. Also the co-operation with the Helsinki authorities has gone well with models.

Rock engineering

Designers are drawing in 2D. BIM coordinator models everything from these drawings. Minimum requirement in this project for rock engineering is to produce 3D dwg format. Rock engineering produces standard drawing- in sections that architecture models to cooperation uses. The goal has been to produce 2D and 3D models at the same time but there have been some delays.

Architecture

1. In the beginning drafting was done with CAD software and the modelling was a bit late compared to the design solutions. At the end of preliminary phase of the project modelling goes hand in hand with the 2D drawings. At this moment where all the disciplines have their models on a good condition the design work can be done modelling based. There have been some delays in modelling work still due to railroad engineering being behind other disciplines in accuracy of the design.

2. After creating the spaces program the modelling work has been done well. All the design has been done model based. References used from other disciplines are mainly in modelling format.

3. BIM is the main design tool. Some sketches have been made in 2D but when ready they have been immediately moved to the model. References used from other disciplines are mainly in modelling format.

Railroad engineering

The software in the modelling sense works differently than the software of other disciplines. In railroad engineering software series of drawing-in section are created. Software then connects these to be continuous model. The model is parametrical and updates itself when changes occur. Software that are used are Citicad, Microstation, Autocad and in the track geometry Bentley Railtrack. The formats produced are 3D dfx and land xml. IFC can't be produced.

Table 6 Summary of use of BIM as a tool by discipline

	Referencing from models	**Design straight in model environment**	**Problems with global coordinates**	**Problems with producing compatible models**
Strcutural engineering	Yes	Yes		
Electrical engineering	Yes	Yes	Yes	
HPAC engineering	Yes	Yes	Yes	
Geotechnical engineering	Yes	Partly		
Rock engineering	Yes			
Architecture	Yes	Yes		
Railroad engineering	Yes	Yes		Yes

Role of the BIM coordinator by discipline

1. Use of BIM	2. Learnings/development suggestions
Use of BIM as a tool by discipline	Modeling accuracy
Role of the BIM coordinator	Good practices, BIM benefits, good co-operation practices
Main needs of information by discipline	Development suggestions

3. BIM from the perspective of city authorities

The role of the BIM coordinator in the project differed in different disciplines. This was quite a lot related on how the discipline was using modelling as a tool. Some of the BIM coordinators were focusing only on larger scale BIM coordinating of the discipline. Below is a list of different BIM coordinator roles in the City Rail Loop project sorted by discipline. If there has been multiple interviewees from same discipline the different answers have been indicated with numbering. The most important role of the BIM coordinators is the one of architectures. Architecture has the responsibility for coordinating the whole design of their area and at the same time the responsibility for coordinating the model producing.

Structural engineering

Managing modelling of the discipline, checking and validating the models to meet the quality requirements, coordinating schedule and resources of the modelling: who does what in what phase and in what accuracy. BIM coordinators tasks also include designing and modeling.

Electrical engineering

Task of BIM coordinator in electrical engineering is more a role of a messenger. The task is to be a communicator between the BIM development group and the designers. Electrical engineering does almost all of their design work in BIM environment and project managers task is to coordinate the modeling and design.

HPAC engineering

HPAC disciplines BIM coordinator works also as a designer. Tasks do not include responsibility of the model content. For example designers themselves are responsible for combining models inside their own discipline and between different disciplines. Tasks and responsibilities include being the messenger between designers and the BIM development group. HAPC BIM coordinator works as a modelling support for the designers. Responsibility is to coordinate and inform the designers on the use or resources.

Geotechnical engineering

BIM coordinator is one of the designers but is responsible for the quality and content of the model.

Rock engineering

Participates the BIM development group and informs the discipline on the modelling matters. Everything that is modelling related goes through the BIM coordinator. Also does all the modelling in the project in the rock engineering discipline.

Architecture

1. Helping and supporting the architects on modeling related issues. Main modeling work is done by the architects. Role of support and technical help was great in the beginning of the project. BIM coordinator works as a central coordinator between all the BIM coordinators in the design area. BIM coordinator is responsible for combining all the models. Combines the models and checks them for clashes and coordinates the clash checking of other disciplines.

2. BIM coordinator is responsible for and coordinates the model producing of all the disciplines in the design area. Developing cooperation with other BIM coordinators in

3. Responsibility of BIM coordinator is coordinating the model producing of the project area. Task is to follow model producing and quality of models produced by all of the involved disciplines. BIM coordinator is one of the architectural designers. Produces model together with other architects. He also works as a support person in technical questions for other architects. Responsibility is also to work as a part of the BIM development group in the project and communicate the handled issues between the group and designers.

Railroad engineering

Interviewee was BIM coordinator at the beginning of the project but has now moved aside from this role. In the beginning the role was to figure out the naming practices and the cooperation with the infrastructure software and the software used by other disciplines.

Table 7 Summary of the role of the BIM coordinator by discipline

	Participates design	Participates modeling	Does all the modeling	Checks model compatibility	Organizes modeling	Messenger of BIM developement group	BIM support for designers	Combining all models
Strcutural engineering	Yes	Yes		Yes	Yes	Yes		
Electrical engineering						Yes		
HPAC engineering						Yes		
Geotechnical engineering	Yes	Yes		Yes	Yes	Yes	Yes	
Rock engineering		Yes	Yes	Yes	Yes	Yes	Yes	
Architecture	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Railroad engineering					Yes	Yes	Yes	

Main needs of referencing information by discipline

1. Use of BIM	2. Learnings/development suggestions
Use of BIM as a tool by discipline	Modeling accuracy
Role of the BIM coordinator	Good practices, BIM benefits, good co-operation practices
Main needs of information by discipline	Development suggestions

3. BIM from the perspective of city authorities

In this section the interviewees were asked what and from whom are their needs of information to advance their own design.

Structural engineering

1. Main need for information to structural engineering comes from the architecture. Architecture includes the needs of HPAC engineering. Referencing information is also needed from the railroad engineering, HPAC engineering and from rock engineering.

2. Main referencing communication happens with architecture. There are a lot of shared interfaces with geotechnical engineering. Railroad engineering was important at the beginning but the significance has dropped as project has progressed. Also the information from existing structures and future structures is very important for structural engineering. This knowledge is handled by architecture.

Electrical engineering

Railroad engineering and the track geometry is a key need of information for electrical engineering. The other main information need comes from the spacing need of architectures. From these comes the need for electrical engineering requirements. From architecture also the amount of possible electrical distribution places is needed and it also affects the need for electrical need of space. In the future also the communication with structural engineering becomes important. With structural engineering the important thing is the points where electrical engineering goes through structures.

HPAC engineering

Main need for referencing information comes from architecture. Other main key information is the connections to systems outside the project. Important is the placing of connections.

Geotechnical engineering

Architectural design is the main source of information. Other important sources for information are the existing structures underground and interfaces with structural engineering.

Rock engineering

Key information to rock engineering comes from architecture and railroad engineering. Other equally important information is existing underground structures and the quality of the rock. Quality information comes from drilling.

Architecture

1. At the beginning the most important sources of information were from the railroad engineering and rock engineering. Vital information were also the space needs of electrical and HVAC engineering. All existing structures also affect the design greatly.

2. At the beginning of the conceptual design the co-operation between railroad engineering architecture and rock engineering is extremely important. When project progresses all design disciplines become important for architecture. Architecture also communicates with the city planners and other authorities.

3. Architecture in this project was at the beginning mainly interested in the railroad design and rock engineering. Also all the existing structures are very important. From other disciplines the main information that is needed is the space need. This becomes especially important with electrical and HVAC engineering.

Railroad engineering

Architecture and bridge engineering are the main interfaces for railroad engineering. Communication with HVAC and electrical engineering is needed with the device placing. Other needed sources of information are fire technique, rock engineering and the knowledge of existing structures.

In the following table these needs for information exchange that raised from the interviews have been collected together. On the left are the disciplines that require information and on the top the disciplines that they require information from.

Table 7 Information needs according to interviews

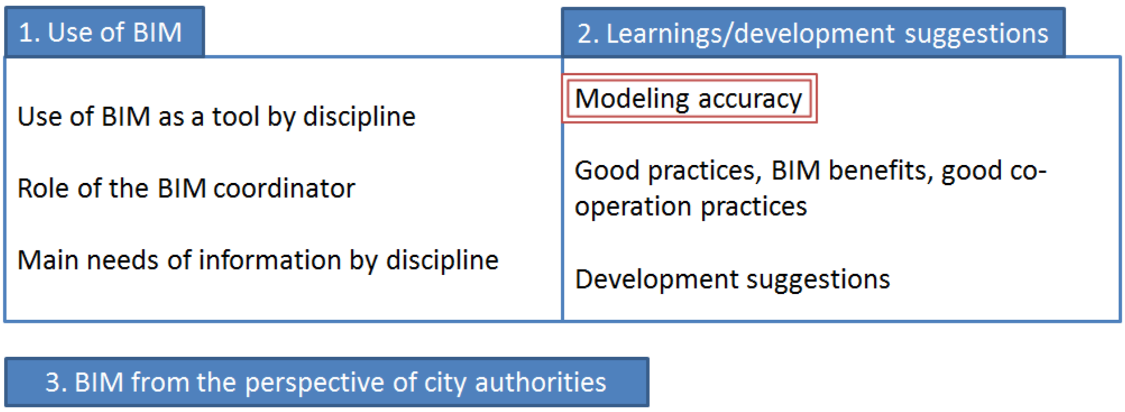
	Main needs of source information between disciplines								
Information user/ Information giver	Architecture	Structural engineering	Electrical engineering	HPAC engineering	Railroad engineering	Rock engineering	Geotechnical engineering	Existing structures	SUM
Architecture		1	1	1	1	1	1	1	7
Structural engineering	1		1	1	1	1	1		6
Electrical engineering	1	1		1	1			1	5
HPAC engineering	1	1	1		1			1	5
Railroad engineering	1		1	1		1		1	5
Rock engineering	1	1			1			1	4
Geotechnical engineering	1	1						1	3
SUM	6	5	4	4	5	3	2	6	

From the table we can see the significance of architecture to other disciplines. This is not surprising for the reason architecture has the overall responsibility for coordinating the design. Other main sources for needed information are railroad engineering and the information about existing structures. It can be said that these three disciplines and their co-operation with other disciplines are the most important design disciplines for the success of the project. It is risky for the project success if these disciplines start performing as a bottle neck for other disciplines.

From the table and interviews it can be concluded that architecture and structural engineering design are the most sensitive for design delays of others.

All of the design disciplines are connected to each other. Still not all show or tell straight relation for the need of source information. This is because this information is communicated through the architecture, which takes all disciplines in consideration.

Modeling accuracy



Interviewees were asked on how the modeling accuracy should develop and what opinions they had in relation of the subject. Answers were quite unanimous.

The general opinion was that the model should match the accuracy of the drawings at all times. The models should include the latest design solution at the exact same accuracy. Models and design should also progress at the same level between disciplines. This point is understandable especially because the models were the main tool and the most useful way for communicating design information between disciplines.

The general opinion was also that the model accuracy should be as low as possible but be able to pass on the required information. Models should follow the set minimum requirements in the project.

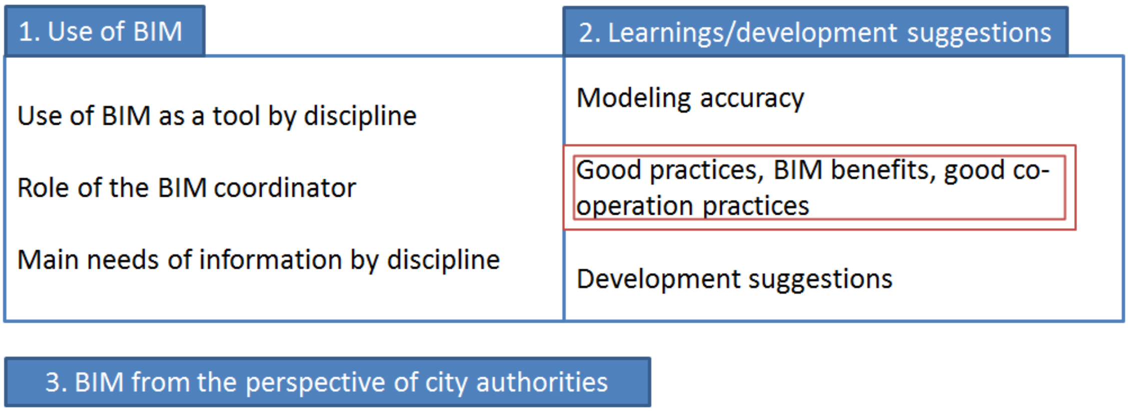
It was agreed that this can’t be the case in interfaces between disciplines. Accuracy of interfaces is something that cannot be set according to standard. Interface accuracy must be defined by case by case. It was also noted that the accuracy should be high in parts of the model that affect the scaling of critical design solutions.

An example of these interfaces needing very accurate level of modeling is the one between the architecture model of the station and the railroad track. In general it could be said that accuracy must be increased in a case of an interface if there is a risk of rework when the interface is detailed later.

In the phase of preliminary design the main communicated matter is the need for space and geometry. This information is critical to be received in model format due to 3D nature of the design. Related to this the general opinion was that the modeling should start already at the very beginning of the project. This should be done even if there is a risk of rework in modeling. Experience in this project shows that starting modeling later in the project caused changes in the design that would have been obvious if modelled at the beginning.

Another point made by the interviewees was that communicating the level of accuracy is a high priority for the project to be successful. It is also critically important to know the exact accuracy of source information.

Good practices, BIM benefits and good co-operation methods



In this section learnings from the projects are gathered together. Following matters were found beneficial in the case project. I have summarized the learnings here as they were not that controversy.

All the interviewees saw the **decision to use and develop BIM practices in this project** as a very positive subject. In interviews no one mentioned that the project suffered from the use of BIM. The opposite was certainly true. Some of the interviewees actually commented: "how could a project this complex be even delivered without BIM." There were also comments that indicated that the use of BIM in other projects had also grown due to good experiences and evolved know-how in this project.

The greatest **benefits from the use of BIM** were seen as its use as tool for communicating information between disciplines. As the project involved such many disciplines, BIM worked as a great visual tool to quickly understand work and design solutions of other disciplines. Designers used BIM to reference other disciplines in order to progress their own design.

Clash checking and confirming compatible design solutions could be quickly seen from the models. Conceiving the design was much easier from models. The case project consists of complex underground tunnels and multiple levels. **Visualizing the geometry** from 2D drawings would have been hard, if not near impossible. At least it would have required huge amount of expertise in understanding on drawings made by other disciplines.

BIM was also used in design meetings. Model was visualized to screens. The part of the design that was under conversation was shown on the screens and all the meeting participants could be sure of the subject under discussion.

To further help co-operation between disciplines, it was seen as an extremely good decision to use **IFC formats**.

BIM has also been extremely good tool in confirming the **quality of the design, functionality and constructability**. Quality comes from the checking that design solutions are compatible. To confirm functionality the project has used different simulations for the models. Constructability and relation to existing structures and buildings have been easily seen from models. In BIM environment it has been also possible to model the different construction phases and temporary space requirements needed used in construction phase.

Implementation of BIM in the project also raised praises. It was seen as a good that the practices and processes have been developed together with the designers in the project. As an example naming practices had to be developed for the project. It wasn't as intuitive because project involved such a many different parties from infrastructure and housing construction. This was done successfully together with the project personnel.

Project formed a **group for BIM development**. They have meetings approximately once a month. Interviewee's opinion was that this had been a great decision. The group consists of BIM coordinators in the project. The forming of the group greatly helped with implementation of BIM to the project. In the group participants could share and solve the technical problems together with other experts. It was also seen as a good way of sharing best practices and processes.

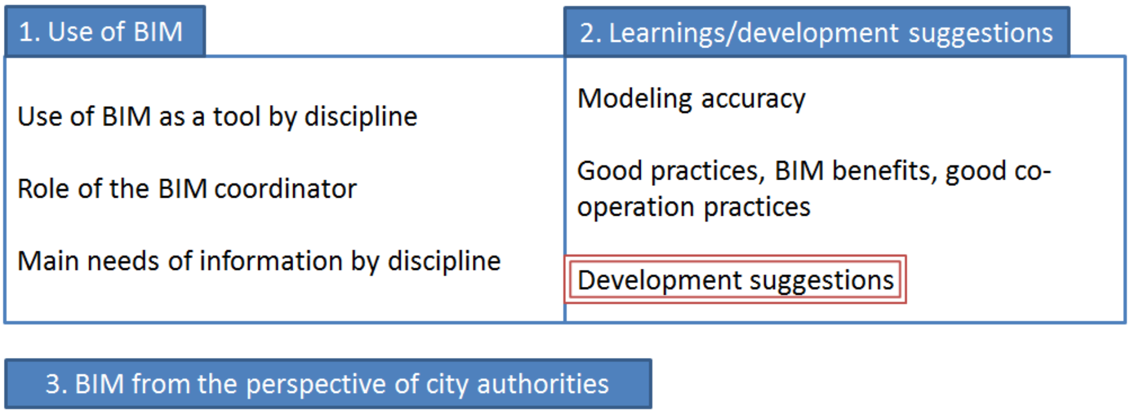
Strategy of **combining models frequently** was seen as a good technique. Especially model based co-operation meetings with two disciplines were seen successful. There the two disciplines will run their models on two screens side by side and go through the whole design to produce compatible material.

As a model publishing technique the project used **freezing of the models** at certain periods of time. This was seen as a good process of co-operation by several interviewees.

To speed up the design, designers used the strategy of using **standardized solutions** where it was possible.

BIM communication with the city authorities was mentioned as co-operation method that had been successful in the case project. Knowledge of BIM matters at the city side got praises. Zoning officials had also access to the common data area and they could actively comment on the design solutions. Collaborating with zoning officials went smoothly because their commenting was sometimes even directive instead of just commenting on published design solutions. By giving their opinions and requirements on design solutions at an early phase of design expedited the design process.

Development suggestions



Interviewees gave several development suggestions for existing processes and working methods with BIM. They vary from the level of larger picture development to quite detail, but still important matters. Here the results of interviews under this topic have been gathered under a framework of **process, people and technology**.

Process related development suggestions

Project members themselves in the case project have developed the BIM related practices and processes. This was seen as a good thing in the interviews. By doing it this way it increases commitment to set practices. But it was also seen as a very time consuming matter. It caused delays because the design work already started when the process was still developed. Suggestion was that the processes should be developed before the starting of design. This doesn't exclude the opportunity to reevaluate and develop the existing process, but there should be a starting point.

During interviews the interviewees also analyzed other reasons for delays in the process. In their opinion the largest delay causing issue was that the design and modeling wasn't progressing at same accuracy with every discipline. Finger was pointed to client design supervisors as well as to colleagues. Interviewees saw the latency of needed referring information to cause delays in their own design process. Suggested solution for this was that these dependencies need to be recognized and informed better. Even a workshop for dependency mapping was suggested.

In addition to disciplines not designing in same accuracy, faults were also found in the accuracy of model compared to the drawings. This was a problem of disciplines that produce models after the design has been completed in 2D rather than making the required drawings from the models. The quality of produced models for co-operation had some critique. For example levels were not matching and "fixed cubes" to help the transforming to different coordinates were missing. Models that were meant for co-operation also had quality issues in the sense of their content. Some interviewees felt that they contained too detailed information and unrelated material.

Reference model creating had some issues that concerned some of the interviewees. There were cases were the reference model was created by separate referrers. In this kind of case different disciplines might be using different references in quality. It also causes overlapping work that could be done once not several by different people. Reference model user must be sure to use the latest versions. Malfunctions in this matter might just be a matter of carelessness. Nevertheless it has a great risk of rework.

Information transfer was criticized also in general. Information on decisions considering certain disciplines didn't reach them on time. So there should more accurate recognition on decision making in meetings. Decision makers should consider more accurately, who are affected by the decision.

Troubling for some project members was the sharing through the common data area. They were afraid of the risk that unfinished material would be used as a reference; even it might not fulfill the co-operation requirements. This can be counted as a same problem as the case of BIM reports. Models were lacking and standardized classification system.

Maybe this is why some project members suggested increase in the amount of smaller group co-operation meetings. This meant meetings that would take place with only involving two of the disciplines. Some of the interviewees also wished courage to try new kind of co-operation methods, such as big-room working.

People related development suggestions

Under this headline the development issues were mainly knowledge related. Some of the interviewees had a perception that the BIM know-how might not be in demanded level with some of the project key participants. Many designers claimed that BIM expertise could be at higher level among design supervisor and among client.

Lack of knowledge was also found in understanding the design of other disciplines. It was hoped awareness of understanding their design requirements and reference demands could be raised. Co-operation skills of some parties in the project were criticized. Interviewees were guessing that this is cause of many participants rarely being involved in such a large multidiscipline project. Especially co-operation between traditional housing and infrastructure players was emphasized.

Few of the people interviewed found juxtapositions among project personnel. In ideal situation the project members of course work according to for the best of the project principle. In juxtaposition cases this doesn't come true. An example of this was contractor-designer juxtaposition that has long roots in construction business. People wished to get rid of these kinds of unnecessary matters.

Technology related development suggestions

The greatest matters receiving negative feedback in these developed practices were subjects of defining origins and coordinates for models. Due to lack of some modeling software to be able to use global coordinates, project members had to develop a local coordinate system together with it. First this defining went wrong because the solution resulted in that the model objects were on the negative side of the coordinates. These caused problems with some software that cannot comprehend with negative coordinates. It was interviewees wish that origin and coordinate defining would be done early on the project to avoid latency in the design process. Also transferring and importing models from global to local coordinates was seen as a matter that slows down the process and increases risks of errors.

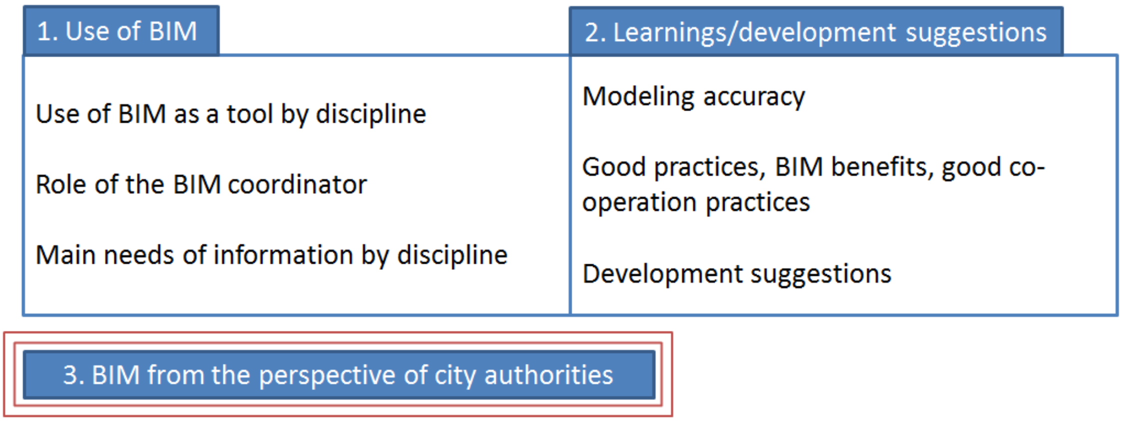
Another technology related subject receiving negative feedback was the use of IFC. It was commented that it was the only reasonable co-operation format existing at this time, but it has its limitations. Exporting IFC format from different software doesn't come without problems. There might be loss of information and other problems during this exporting. IFC is format designed for the housing sector of construction. This is why there were problems transferring format from infrastructure formats to IFC.

Interviewees had discerned that information provided by the pure model is not enough. Project had delivered a BIM report document alongside the models. This document was meant to describe the content and accuracy of the model and changes in the revisions. Updating this document on time was lacking consistency, even though it is a significant for the success of collaboration. Comments in the interviews also indicated that the document was also lacking uniform standards. Variations in the quality of the document could be perceived.

Other problems causing technical issues were:

- Mixed 2D and 3D techniques
- Size of the models
- Laser scanning accuracy

BIM from the perspective of city authorities



The interviewee was working as a project manager from the side of city. Interviewee's role at this phase of project was to analyze the design from the perspective of city zoning. The most interesting part of the design for city authorities was the projects interphases between existing and planned parts in the city. Tasks of project manager also included preparing needed material for decision makers of city of Helsinki.

In the case project the city authorities had also access to the common shared data area. They could follow the design solution progress in real time. This way authority could comment and direct the design actively and without latency.

Models provide a good way to conceive the ensemble of the design. They also give insight in how the design should be presented in the zoning documents.

Interviewee had used models to reference to check clashes to existing zoning. Screenshots from models had been beneficial for preparing decision making material for city authorities. Although, his opinion was that models can be hard to understand for lay decision makers without professional knowledge of construction. Most useful material for lay decision makers has been the traditional 2D drawings.

Models have provided in this project most of the needed information for the city authorities. Only in some cases the referring had to use 2D drawings to perceive more accurate results.

Models have had some technical issues. There have been some cases where models have required format or other transformations to be useful for authority referring. Another technical issue was with the commenting tools of models. Full benefits from the model commenting tools of models weren’t achieved due to data protection issues of the city. Interviewees' opinion was that in the future the dialog inside the model could be a beneficial tool for communicating between authorities and project personnel.

The most challenging part of the project from the city viewpoint has been the underground construction. Helsinki has a lot of underground structures. Models have provided an efficient tool for studying this underground world.

This project has shown that co-operation with city authorities can be done through models. The next step in development for the city would be to develop the model requirements for zoning and other authority needs.

Summary

Interviews gave great amount of insight in the current uses and benefits for using BIM in projects. Possibilities of BIM had been implemented very well in this case project. Room for development especially in the co-operation was also found.

The results of interviews were probably the most valuable part of this thesis. This is because the interviewees all were professionals in the everyday use of modeling.

Next section will provide more process emphasized approach for the co-operation in the case project.

4.2 Project meetings analytics

The goal of this analytics was to form insight in how BIM is used among designers and what kind of co-operation and processes are related to that.

Three different groups were followed for analytics during this thesis. They included the co-operation meetings of three different design groups. Design groups here are referred as A, B and C. They do not refer to the group naming in the actual case project to preserve anonymity.

Meetings that were participated for analytics:

- Design group A co-operation meetings x 3
- Design group B co-operation meetings x 4
- Design group C co-operation meetings x 4

Meetings were followed during at the end of preliminary design phase of the project.

Other meetings were also participated including BIM development group, clients BIM development group and other design meetings to clarify thesis writers overall picture on the project.

Found model co-operation processes:

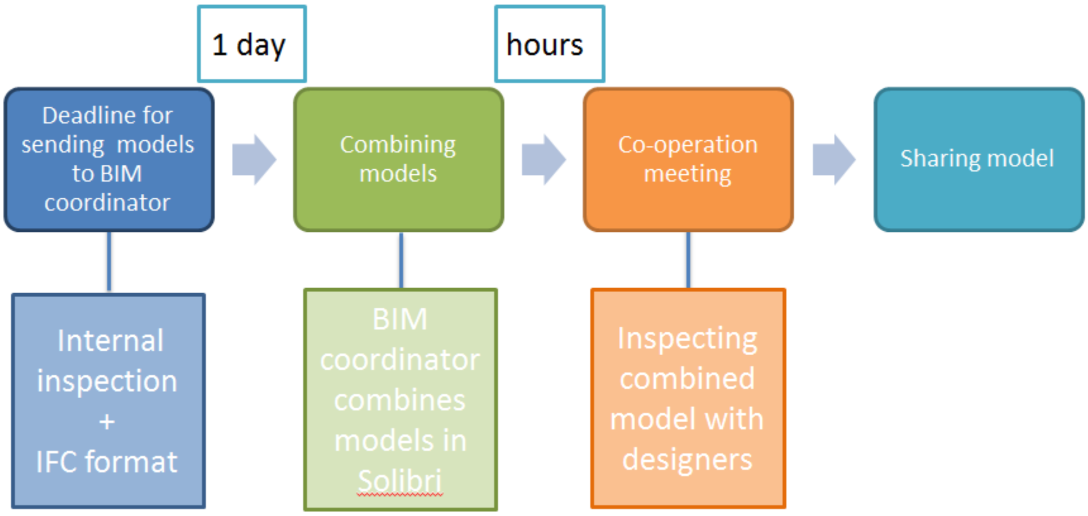


Figure 13 Group A co-operation process

Group A repeats this process every two weeks. Architecture BIM coordinator gathers and combines the models into a single model. The actual inspection work is done in the co-operation meeting, where the largest clashes are observed visually. BIM coordinator does this inspection work between these meetings. Results of this inspecting are communicated in the meeting. Models are in “freeze” state when they are sent to the BIM coordinator.

In the co-operation/collaboration meeting representatives from all necessary design disciplines are present. The representatives should be designers with an overall view over the area inside their discipline. Found clashes may result in new kind of design solutions and this is why representatives in the meeting need to have design expertise.

Combined model is run on the screen in the meeting room. Inspection takes place discipline by discipline. For example first architecture model is compared to structural engineering and then to HVAC.

For an outside observer, the time between combining models and actual meeting seemed too tight. There should have been time to inspect the model properly before the meeting to get maximum benefit from the meeting.

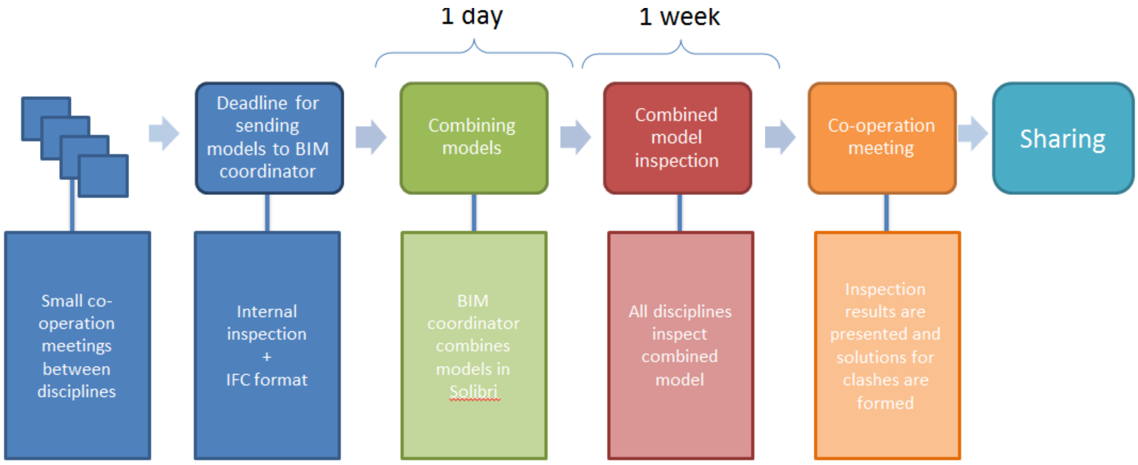


Figure 14 Group B co-operation process

Group B took a heavier approach in achieving compatible models compared to group A. The presented process took place when the group members agreed on that the model accuracy of each discipline has achieved a level where this kind of clash checking was reasonable.

During the preliminary phase of design group B kept co-operation meetings between two disciplines. In these meetings the models were run on two screens side by side and compared to each other in order to find clashes and make them compatible.

When the model accuracy of all disciplines had reached a point where the process could begin, first the models were put in freeze state and sent to architecture BIM coordinator. BIM coordinator combined models and shared the result to disciplines. Disciplines had a week to inspect the models and make a list of errors in the models. These lists of errors were then presented in the co-operation meeting and then discussed when necessary. In the meeting not only errors were presented to the group but also the areas where models were compatible were shown. This was a good thing, because it clarifies for the participants that there is no need to further inspections in that area.

After the co-operation meeting design group fixed the presented problems in the models. After that the models were combined weekly and inspected by the BIM coordinator.

During the whole preliminary phase group B also was freezing models weekly. They were inspected by the BIM coordinator and the results were presented in the weekly design meeting.

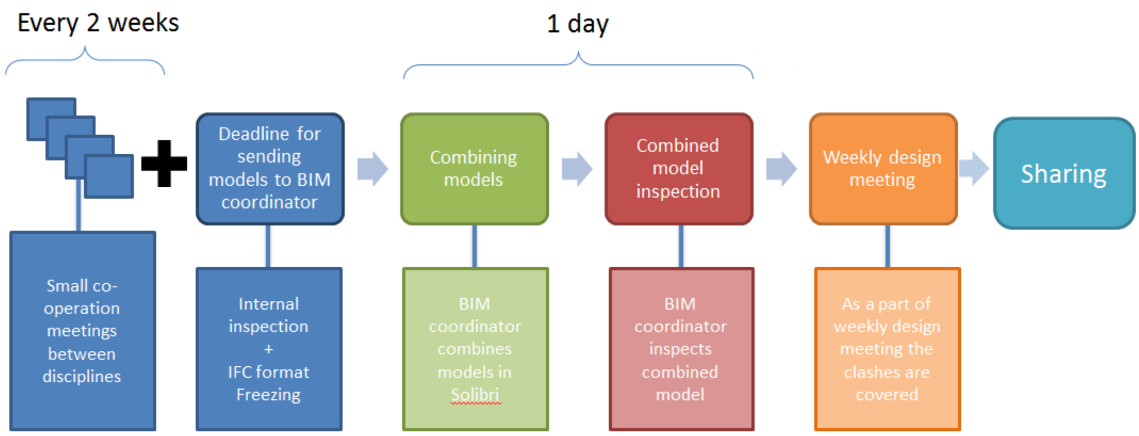


Figure 15 Group C co-operation process

Group C had smaller co-operation meetings every two weeks or more rarely when necessary. There two or more disciplines were present to cover clash detection matters.

They covered compatibility issues in their weekly design meeting. Before the meeting BIM coordinator received models, combined and inspected them.

The result is that all three groups had selected different methods for their co-operation with models. Two of them handled model clashes and compatibility issues as a natural part of their weekly design meeting. This is continuous method and the right people are aware of these issues because of that.

Group A was lacking efficiency in the meetings because the inspection wasn't properly gone through before the meeting but in the actual meeting. In group B: s process it was good that all the disciplines were harnessed for the inspection work. This produced a compatible design efficiently compared to the other two processes.

Picture 6 Picture from co-operation/collaboration meeting

Picture above has been taken from a co-operation meeting. There it can be seen that BIM coordinator goes through the model inspection results using model commenting tool.

Summary

All the three design groups had a different approach on producing compatible models.

The best results were achieved in the most heavy co-operation process where all the disciplines were included in the checking of the models. This is a good way for final combination of models for example in the end of certain design phase. But it is too heavy to be used constantly throughout the design.

As in the results of the interviews also in this analyze the smaller meetings between design disciplines were greatly beneficial. More accurate results can be achieved without wasting the time of other disciplines that can happen in larger meetings. Need for larger information sharing and co-operation nevertheless exists.

These points are taken into consideration when suggesting a co-operation process for producing compatible models in conclusions section of this thesis.

Next chapter analyzes the common data area to study the dependencies between design disciplines.

4.3 Common data area analytics

From the log of the common data area, also called project data bank, I will analyze what has been information flows in this project. The inspiration for this analyze is the method developed by Reid Robert Senescu et al (2012).

The common data area or sheared data bank that was used in the case project was VDC Stream by Viasys VDC Oy. Beneficial feature of the program was that it collects time stamps on each action made in the system. This feature provided the possibility to do the analytics for dependencies.

Designers of the case project were encouraged to use common data area as their main source for information exchange. This increases the reliability of the analytics.

Collected data:

- Who has produced material and when
- Who has downloaded material and when -> indicates the need for information
- Which parties are the biggest users of the project bank

Data parameter requirements:

- Time
- Separation of data by different design groups
- Separation of data through personnel

Results of analytics: information dependencies in the design process as a parameter of time.

Use of result: improvements to the existing process: when and what kind of meetings and information exchanges are required.

This analytics method does not include the other information exchange in the project: meetings, e-mails etc. But as the paper Generating a Network of Information Dependencies Automatically (2012 Senescu, Head, Steinert, Fischer) shows, the information exchange through the project bank correlates with the other information exchange in the project.

Project bank data includes upload data of 40000 rows and 270000 rows of data of different actions. In project bank there are 276 different downloaders from 39 different companies. The total results of analyze and examples of analyzed data can be found from the appendix section of this thesis.

Analytics was done to find out the dependencies between different groups in the project. This was done comparing the project bank data downloads and uploads. From the data it was researched which design field uploaded and downloaded a file based on their e-mail address. Matrix was formed comparing which design field had downloaded data produced by a different design field. In the first column of the matrix are the uploaders of files to the project bank and on the first row the downloaders. Extracting only downloads from the original data reduced the amount of downloads to 63000 files.

First common data area log data was converted to excel. Matching downloads with uploaded files was done by comparing the file name. Dependencies between design groups were found out through the users e-mail address. Downloaded file was connected with an upload file and the matrix was formed comparing amount of downloads between these companies.

UPLOADS/DOWNLOADS	Structural Engineering 2	Street and Traffic Planning	Structural Engineering 1	Rock and geo engineering 1 and structural engineering 1	Helsinki City Planning Department	Rock Engineering 2 and 3	Architect 3	Geo Engineering 2 and 3	Source Information Engineering	HVAC, Water and Electrical 1 Engineering	Track Engineering	Developer and Project Management Consultant	Architect 1	BIM Responsible Architect 2	Project Bank Service Provider and BIM Consulting	Architect 2	BIM Responsible Architect 1
1. Source information engineering	[illegible]	166	[illegible]	[illegible]	137	221	309	[illegible]	102	139	289	202	235	298	211	45	[illegible]
2. Rock and geo engineering 1 and structural engineerin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	169	94	205	[illegible]	124	[illegible]	177	447	6	175	20	45
3. Rock Engineering 2 and 3	[illegible]	[illegible]	[illegible]	138	[illegible]	[illegible]	[illegible]	215	[illegible]	81	113	91	4	65	61	230	
#N/A	[illegible]	[illegible]	418	[illegible]	[illegible]	249	387	183	251	279	298	219	198	51	76	45	13
4. Geo Engineering 2 and 3	[illegible]	[illegible]	344	363	135	[illegible]	382	215	447	16	33	13		78	32	101	
5. Architect 3	117	[illegible]	[illegible]	156	316	[illegible]	83	243	23	318	145	206	53	46	23	60	
6. Track Engineering	68	350	373	436	150	245	299	107	167	240	257	99	141	83	81	82	28
7. Structural Engineering 1	90	[illegible]	163	210	214	20	275	291	98	26	173	61	6		32		1
8. BIM Responsible Architect 2	136	133	8	32	154	107	38	77	20	175	45	76	8	15	15	57	5
9. Structural Engineering 2	60	269	202	73	143	82	13	55	4	18	11	5		191	1	40	1
10. Architect 1	11	145	30	166	158	1	28	2	7	216	68	86	70	38	3	19	20
11. Developer and Project Management Consultant	188	48	53	52	16	79	108	44	13	38	7	95	25	23	1	32	1
12. Project Bank Service Provider and BIM Consulting	83	82	78	117	128	20	43	34	25	24	7	52	38	13	15	2	3
13. Street and Traffic Planning	49	243	10	8	60		52	19	2		135	13	45	3		1	
14. Architect 2	52	110	19	19	94	47	32	15	20	85	15	72	7	4	3	14	
15. Helsinki City Planning Department	214	1		37	3	26	2	75	35	2		3		175	1	11	
16. HVAC, Water and Electrical 1 Engineering	22	13	48	43	40	1	54	1		77	6	37	2	4	23		10
17. BIM Responsible Architect 1	4	37	9	77	27	4	6			106	4	20	4	3	16		6
18. Acoustics Engineering	56	30	64	11	52	39	48	1	24	6	1	9	4				
19. Electric Track Engineering	9	20	62	27	18	13	20	4	2	19	9	3	17	1	12	8	
20. Fire Safety Engineering	14	11	33	9	26	6	23	2	2	59	9	30	17	4		5	
21. Electrical Engineering 2 and Automation Engineering	33	62	50	11			20		3	20	1	1	4	2	39	3	5
22. BIM Responsible Structural Engineering 2	20	25	29	11	16	14		8		11		12		20	15		
23. Railway Safety Planning	106	12	2	9		3	3	2		4	1	2	6			1	
24. Project Management Sub Consultant	5	3	10	17		1	13	4		5		3	5				
25. Communications Consultant					10							4					
26. Traffic Planning	8	14	4		10	1	4	2				4					
27. Ground Water Consultant		4	7	2	6	9	6	3	8	1	1	1					
28. Electrical and Automation Engineering														10			
29. Radio Network Planning			16									2	5				
#NAME?	2		1							1					2		
30. Finnish Transport Agency					2							2					
Grand Total	13268	8860	4837	4739	4606	3041	2851	2803	2711	2090	2076	1600	1341	1131	835	776	647

LEGEND

(red)	TOP 30
(pink)	TOP 100

Table 8 Part of the dependencies matrix

From this data we can quickly see that the DSM Matrix tools cannot be applied to find out in which order the design should be done. It can also be seen that dependencies do occur between most of the design fields. Even DSM cannot be applied; there are several conclusions that can be made from this data.

First conclusion is that all the design fields are extremely dependent on each other. Large scale co-operation is definitely needed among design fields. It can also be seen that the most downloaded files at this phase of the project are the source information gathered before the start of the design. It emphasizes together with the interviews that the source information was really well produced in this project as well as it was greatly usable and great data for the design phase.

It can be seen that the most important design fields from the viewpoint of the project are the most active ones in the data. Notification can be made from the use of combined models. All the files produced by Architecture BIM responsible are highly downloaded. The main files that they have produced are the local combined models of the stations. Conclusion is that the combined local models have been highly successful and useful for the design of this project. This conclusion is also supported by the interviews.

In the listing below are the most downloaded design fields in this project:

1. Initial data engineering
2. Rock and geo engineering 1 and structural engineering 1
3. Rock Engineering 2 and 3
4. Geo Engineering 2 and 3
5. Architect 3
6. Railway Engineering
7. Structural Engineering 1
8. BIM Responsible Architect 2
9. Structural Engineering 2
10. Architect 1

From the resulting matrix it can be seen that the original data has not been completely satisfactory and complete. The amount of downloads not matching with uploads is almost ten percent of the whole data. Also not all data exchange has been through project bank. There has been exchange of data and information through meetings, e-mail and phone calls also. But I think the size of the data still is still valid to make the previous conclusions made above. The mistakes result from the shaping of the original data. Downloaded files and uploaded files were not comparable at first. They had to be modified in excel. The download data was in format of one single line of text. They were separated with excel functions and this caused some errors with naming of the files. The modifications made to make them comparable were no completely satisfactory.

Analytics was also made without source information engineering as it was so dominant over the other dependencies. In this analyze the files with no match were also excluded. From this table we can take slight conclusions on what are the most significant design fields in this particular project. The table also shows the largest dependencies. Cells with light red are cells that had information exchange over average of 67 file downloads. Cells with deep red are top 30 dependencies.

From this table we can also see the advantages of using a single project bank with open data for everyone. It is obvious that there has been information exchange over design team borders. For example structural engineering 2 is number one in downloads from rock, geo and structural engineering 1.

Dependency UPLOADS/DOWNLOADS	Structural Engineering 2	Street and Traffic Planning	Structural Engineering 1	Rock and geo engineering 1 and structural engineering 1	Helsinki City Planning Department	Rock Engineering 2 and 3	Architect 3	Geo Engineering 2 and 3	HVAC, Water and Electrical 1 Engineering	Track Engineering	Developer and Poject Management Consultant	Architect 1	BIM Responsible Architect 2	Project Bank Service Provider and BIM Consulting	Architect 1	BIM Responsible Architect 1	Fire Safety Engineering	Electric Track Engineering	Ground Water Consultant	Sakko.fi	(blank)	Electrical Engineering 2 and Automation Engineering
2. Rock and geo engineering 1 and structural engineering 1, BIM responsible Architect 3	556	2804	516	1128	2093	169	94	205	124	448	177	447	6	175	20	45	16	14	20	2	167	8
3. Rock Engineering 2 and 3	484	834	779	138	1089	474	513	215	81	113	91	4	65	61	230		15	55	216	124	50	11
4. Geo Engineering 2 and 3	560	1317	344	363	135	744	382	215	16	33	13		78	32	101		2	1	191	54	32	
5. Architect 3	117	814	616	156	316	466	83	243	318	145	206	53	46	23	60		168	25	4	20	25	77
6. Track Engineering	68	350	373	436	150	245	299	107	240	257	99	141	83	81	82	28	47	158	1	1	13	8
7. Structural Engineering 1	90	484	163	210	214	20	275	291	26	173	61	6		32		1	2	8	2		39	25
8. BIM Responsible Architect 2	136	133	8	32	154	107	38	77	175	45	76	8	13	13	57	5	78	6		93	6	6
9. Structural Engineering 2	60	269	202	73	143	82	13	55	18	11	5		191	1	40	1	2	1		102	1	1
10. Architect 1	11	145	30	166	158	1	28	2	216	68	86	70	38	3	19	20	39	2			16	6
11. Developer and Poject Management Consultant	188	48	53	52	16	79	108	44	38	7	95	25	23	1	32	1	17	26		4	2	28
12. Project Bank Service Provider and BIM Consulting	83	82	78	117	128	20	43	34	24	7	52	38	13	15	2	3	10	91		7		
13. Street and Traffic Planning	49	243	10	8	60		52	19		135	13	45	3		1			4	1	8	2	1
14. Architect 1	52	110	19	19	94	47	32	15	85	15	72	7	4	3	14		19	2		20		6
15. Helsinki City Planning Department	214	1		37	3	26	2	75	2		3		175	1	11		1			8		
16. HVAC, Water and Electrical 1 Engineering	22	13	48	43	40	1	54	1	77	6	37	2	4	23		10	1	1			10	14
17. BIM Responsible Architect 1	4	37	9	77	27	4	6		106	4	20	4	3	16		6	13	1			12	1
18. Acoustics Engineering	56	30	64	11	52	39	48	1	6	1	9	4					1					
19. Electric Track Engineering	9	20	62	27	18	13	20	4	19	9	3	17	1	12	8		11	37				1
20. Fire Safety Engineering	14	11	33	9	26	6	23	2	59	9	30	17	4		5		39	4				3
21. Electrical Engineering 2 and Automation Engineering	33	62	50	11			20		20	1	1	4	2	39	3	5						4
22. BIM Responsible Structural Engineering 2	20	25	29	11	16	14		8	11		12		20	15							7	
23. Railway Safety Planning	106	12	2	9		3	3	2	4	1	2	6			1			3				23
24. Project Management Sub Consultant	5	3	10	17		1	13	4	5		3	5					1					9
25. Communications Consultant					10						4										2	
26. Traffic Planning	8	14	4		10	1	4	2			4											
27. Ground Water Consultant		4	7	2	6	9	6	3	1	1	1											
28. Electrical and Automation Engineering													10									
29. Radio Network Planning			16								2	5										
30. Finnish Transport Agency					2						2											
Grand Total	13268	8860	4837	4739	4636	3041	2851	2803	2090	2076	1600	1341	1131	835	776	647	614	588	523	475	434	297

LEGEND	
(deep red)	TOP 30
(light red)	TOP 100

Table 9 Part of dependencies matrix without source information engineering and files without matches

When the amount of file exchange is researched we can find the key design teams in this project. Dependencies between them are shown below.

Dependency												
UPLOADS/DOWNLOADS	SE2	STP	SE1	RG1 & SE1	HCPD	RE2 & 3	A3	GE2 & 3	HVACWE1	TE	PM	A1
Rock and geo engineering 1 and structural engineering 1, BIM responsible Architect 3	556	2804	516	1128	1093	169	94	205	124	448	177	447
Rock Engineering 2 and 3	484	834	779	138	1089	474	513	215	81	113	91	4
Geo Engineering 2 and 3	560	1317	344	363	135	744	382	215	16	33	13	
Architect 3	117	814	618	156	316	466	83	243	318	145	206	53
Track Engineering	68	350	373	436	150	245	299	107	240	257	99	141
Structural Engineering 1	90	484	163	210	214	20	275	291	26	173	61	6

Structural Engineering 2	SE2
Street and Traffic Planning	STP
Structural Engineering 1	SE1
Rock and geo engineering 1 and structural engineering 1	RG1 & SE1
Helsinki City Planning Department	HCPD
Rock Engineering 2 and 3	RE2 & 3
Architect 3	A3
Geo Engingeering 2 and 3	GE2 & 3
HVAC, Water and Electrical 1 Engineering	HVACWE1
Track Engineering	TE
Developer and Poject Management Consultant	PM
Architect 1	A1

Table 8 Dependencies of the design fields with the most file exchange in the project

From the second analyze it can be also seen that the most downloaded design fields accumulate quickly in the percentage of total downloads. From the figure below it can be seen that the three most downloaded design fields already total 50% of the total downloads. This refers to their importance. This importance further means, from the perspective of the design process, that they are the critical in the success of the project. Analyze indicates that their involvement and their documents are the most critical in the view point of other design fields being able to do their work properly.

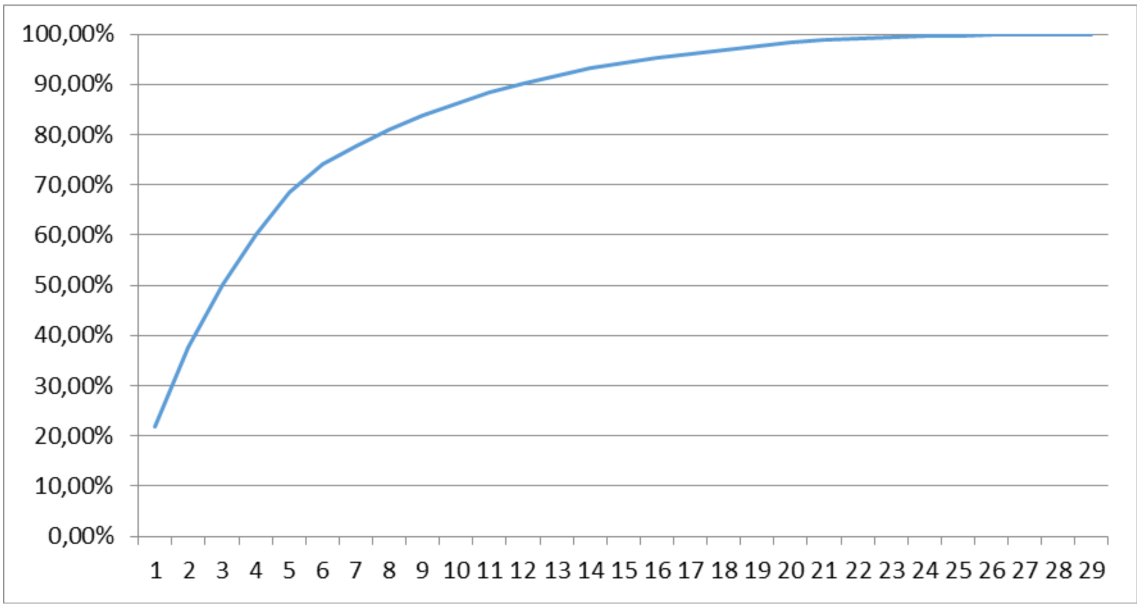


Figure 16 Percentage accumulation of total documents produced by the order of largest document producers

From the same original project bank data it was also made a research of latencies in the process. In a matrix it was compared average latencies between design fields. This was done by comparing the upload time of a file and the download time of that specific file. From these it was collected an average time that it took from some design field to produce a file to when some other design field had downloaded it.

It is hard to make any conclusions from this data because it is impossible to look to certain files. It would be important to know the files significance and type of the document as well as the content to be able to make conclusions on how much there really are latencies in the process. For example the source information was produced before the design and these should show great latencies as they actually do show in the matrix collecting the averages. Also the upload data shows only the first time that a single file was produced, not the upload time of the different revisions of that file.

UP/DOWN	insmetsarinne.f	gravicon.f	massivedy	kolumbus	vianova.fi	proxion.fi	vr.fi	omnitele.c	vtt.fi	e-west.fi	arcadia.fi	granlund.f	jsund.fi	ins-niemi	trafix.fi	liikennev	poyry.com	ramboll.fi	L2.fi	wspgroup	hel.fi	sweco.fi	finnmap-i
vianova.fi	157	[illegible]			151	[illegible]	[illegible]	[illegible]			178,6667	[illegible]	136			[illegible]	[illegible]	[illegible]	157,7	[illegible]	[illegible]	203,7308	[illegible]
vr.fi			[illegible]				[illegible]					[illegible]		126,7778		157	[illegible]		[illegible]	155,1		216	221,6667
jsund.fi	138,25	221,3333			197,8667							[illegible]					[illegible]			180,2069	[illegible]	130,6667	[illegible]
sipti.fi	[illegible]				223	[illegible]	204,3235	187			177	154,6111	222,5833	[illegible]			121,2055	155	186	139,0792	216,1399	133,8	167,1933
arcadia.fi	[illegible]	184,0455			188,1875	[illegible]					176,3333	137,1321		196		[illegible]	134,3117		138,6923	124,8889	203,9259	153,3	155,3784
sweco.fi		165,5	[illegible]		3	[illegible]	176,875	123,5			[illegible]	179,2105	129,5	60,03571	[illegible]	162,1818	156,5962	132,4615	153,9412	101,4717	152,5625	178,4947	179,875
sito.fi	[illegible]	128	22	[illegible]	184,7531	158,3544	113,1875	[illegible]		114,4	164,2857	116,1208	203,82	81,625	100,6667	125,4615	149,5367	129,7246	131,1064	115,2279	120,5133	125,5253	139,2286
arkkigraf.fi	112,9090909	[illegible]		[illegible]	[illegible]	220,8333	115				170,2	106,5943	76,38298	45,5	[illegible]	143,4706	114,0625	159,95	87,88462	216,125	86,38961	131,0658	105,2481
poyry.com	125,3333333	190,0741		4	174,1543	122,8571	[illegible]	182,8776		132	190,2667	97,89516		[illegible]	40,5	128,5714	128,8537	166,7672	161,3125	141,7984	135,6167	134,8927	118,163
ains.fi	127,097561	168,5		182	162,625	139	129,5952	146				119,75	193		69	114,5	139,1846	181,1588	74,5	100,689	120,3111	134,4615	119,0478
sroy.fi	221,2			155,42	[illegible]	111,7091	50,71429	[illegible]				77,98765	[illegible]	54,63636	192	130,6667	127,0942	140,5057	61,93333	111,6406	136,2185	176,2637	150,9101
wspgroup.fi	180	143,3889			102,5313	87,5	[illegible]	159,4444			15	190,0769	144	206,36	70	91,68421	120,8762	85,15306	97,5	154,2699	85,64953	88,37705	99,75826
pesark.com	208,675	209,1667		43	173,5652	66,44	209,6	130,5294				112,7579		121,1429	93	136,5714	100,859	89,52174	123,4464	110,8366	129,4051	74,18447	86,55774
proxion.fi			119,2		87,83333	143,5135		116,5833		179,4211		118,2105		81		48	163,5185	129	86,81818	143,1613	117,7222	103,6667	140,85
hel.fi	37,5				23		145					128,5				49,33333	70,43243	25,94286	182		88	134,6667	14
akukon.fi							185	129,6667				202				25	73,81818	52,20833	46	154,8438	40,55769	34,88889	18,06667
arkdt.fi	110,3333333	117			69	170	[illegible]	95			138,4	98,52778		177		50,09091	69,92771	47,71429	98,92308	76,83333	64,06962	55,39535	79,98621
trafix.fi							6								110					161	102,7	40,75	142,4286
cjn.fi					178,6667	69	7					88,07059		53,83333		66,33333	100,6842	88,3	60,10526	113,1579	88,34043	104,6667	81,16364
waterhope.fi							21					139					3	57,625		35,57143	103,1667	148	29
ins-niemisto.fi					182,9487		76,75	135			61	138,05	39	152,25	93		66,81818	115		125,56		49	96,32258
acsanafor.fi																124,6923					39,7	57	
L2.fi			51,875			18,75		40	142,25			62,28814		123		40,42857	49	58	56,17949	34,81818	76,84615	91,06667	27
finnmap-infra.fi						15								106	88,13043		58,5	154		43	51,96667	80,38462	94,00412
massivedynamic.fi						105,6667	23					28		139,1739		219,5	60			7		214,5	1
liikennevirasto.fi																84					4,5	98,5	
granlund.fi		36,46667			96,82609	186	158	11,5			5,4	88,67532	38	63,14286		70,5	70,11628		15	66,66667	52,925	81,86486	40,07692
omnitele.com								2												7,5		0	
tauno-nissinen.fi													11										
AVERAGE	180,933204	169,459	155,3864	153,7367	150,3931	149,4553	143,9129	143,0759	142,25	141,9404	139,5957	135,3079	130,3897	130,3321	128,3906	119,4726	119,1717	118,0017	115,7917	115,7302	113,7256	113,3969	111,7919

LEGEND	
(red)	TOP 30 Latency
(light red)	Above 50% Latency
(green)	MIN 30 Latency
(light green)	Below 50% Latency

Table 9 Example of Average Latency Matrix

The project bank data was also sorted with a listing of researched design teams and commissions. This was done by matching the names of downloaders and uploaders with a list that has them connected with the commission. This analyzes shows similar conclusions as the previous ones. This analyze can also be more affected to errors due to differences in their real name and e-mail address.

UP/DOWN	KATU	KAT2	RAK2	RAK3	ARK3	LVI	KAT1	ARK2	ARK1	JOHS	SA,Talote	Palotekni	RAK1	RM-Runko	SR	IR141024,	KAT3	Riskienha	TOTAL
KAT2	2082	1615	1134	1028	995	84	216	345	4	277	13	16	3	30	56	2	5		7905
ARK3	867	555	152	642	225	301	151	108	57	52	98	168	1	66	28	17	23		3511
KAT1	854	216	318	280	47	72	417	140	327	13	13	7	85	13	3	15	2	1	2823
JOHS	1620	170	195	39	141	24	177	12	103	189	9	7	10	9	4	8	16		2733
ARK2	243	241	348	26	71	242	11	88	21	32	184	97	13	29	8				1654
RAK2	294	157	200	231	18	26	4	251	1	53	7	2	22	5	1	1	2		1275
ARK1	224	9	15	12	97	202	56	60	107	35	131	52	96	12	3	4			1115
RAK3	225	176	43	39	299	17	17		6	10	20	2	6	1	4	5	8		878
KATU	346	73	86	39	107	5	11	4	52	16	4			11	7	11	2		774
RAK1	140		87	76	5	7	39	1	46	13	5		32	2	1				454
LVI	13	2	26	48	89	76		4	12		13	1	4	1		2			291
RM-Runkomelusuunnittelu	41	40	56	51	48	6	9		4			1	1	5		6			268
SA,Taloteknninensähkö-jaautomaatiosuunnittelu	62		46	50	33	12		15	9		24				1	5			257
SR	20	13	9	62	23	14	4	9	17	7	9	11	1		37	12			248
Palotekninensuunnittelu	12	8	14	32	24	59	6	9	17		3	39	1		4	5			233
IR141024,Radioverkkosuunnittelu				16					5							2			23
Riskienhallinnanasiantuntijapalvelu																			0
TOTAL	7043	3275	2729	2671	2222	1147	1118	1046	788	697	533	403	275	184	157	95	58	1	24442

Table 10 Dependencies sorted by commissions under research

Overall analyzes on the dependencies are interesting. When they are compared with the dependencies announced by the interviewees, many differences can be found. Project bank data shows much more dependencies between design fields than the interviewees reported in the interviews. This shows lack of designers understanding fully the actual dependencies in the project. This suggests that defining dependencies in order to organize and timetabling planning is an area that should be improved.

5 Results and discussion

In this part of the thesis results from the analytics and theory study are gathered together. A suggested process to produce compatible models and suggestions to further develop BIM based design management are formed based on these results.

5.1 Suggested processes to produce compatible models

One of the goals for the master's thesis was to create a process that would efficiently produce compatible models and that way produce better quality in design. As a result there can be seen a three different processes to suit different situations in the process to achieve compatible models.

Firstly, the three different design groups studied in the thesis had seen a need for continuous updating and combining process for the models. Their approaches differed slightly, achieving different results. BIM coordinators of each discipline together with the architecture BIM coordinator had this process as their responsibility. Main responsibility for coordinating the process was with architecture BIM coordinator.

Suggested three processes are:

- Continuous co-operation process
- 'Bottle neck' discipline co-operation
- Final integration of models

Continuous co-operation process

Suggested continuous co-operation process is a result of putting together the best parts of already used processes in the case project. This combination compounded with findings from the BIM guidelines.

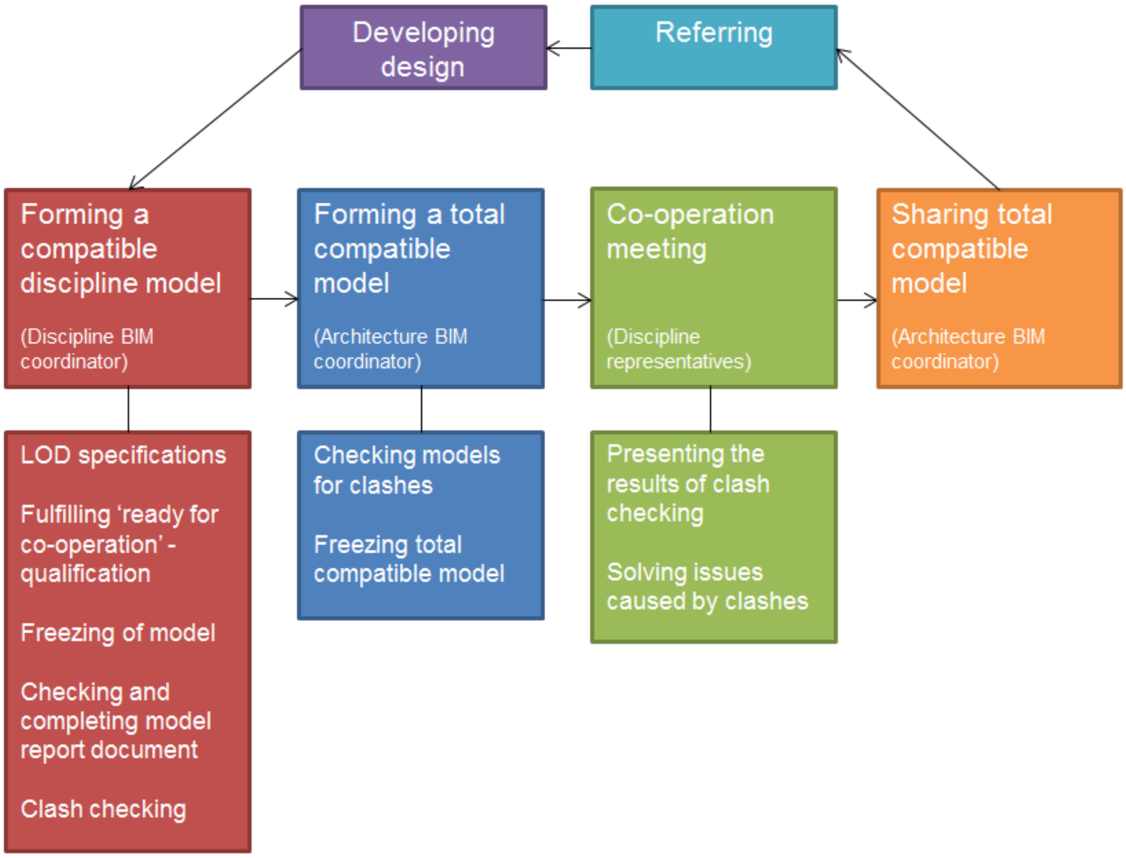


Figure 30 Suggested process for continuous model producing of compatible models

Continuous co-operation is a cycle that repeats itself. Timeline for repetition should tight enough for the design to be able to use the latest material. Suggested cycle is one or two weeks depending on the design intensity.

Cycle starts from **forming a compatible discipline model**. Discipline BIM coordinator gathers the models that the discipline has produced and compiles them together. **Clash checking** is performed to the model.

Elements in the model are produced in agreed **LOD** level. Designer of the model is responsible for producing elements accordingly. BIM coordinator performs checking of elements for LOD level.

Status of the model is checked to match the agreed specifications. Status as well as LOD progresses as the design develop, according to the BIM execution plan and design requirements. For model to be referable it needs to fulfill the requirements for status 'ready for co-operation'.

'Ready for co-operation' status definition must be defined together with other designers in the project. To get the status the model must meet the referring requirements set by the needs of using disciplines. The main information that needs to be communicated between disciplines is geometry, volume/size, orientation and location. These matters must be in a level of detail that they are possible to refer in certain phase of the design. Status qualification also includes the agreed model format for referring.

Due to the current state of the modelling software's and capabilities of computer hardware, co-operation models shouldn't have any extra information than is needed. **Simple models**, that include only material that is needed by other disciplines, are the most usable ones.

Revision history of the model needs to be followed as well. **Model report document** includes the information of LOD levels, status of the model and revision history of the model. This is a very important part of co-operation. The document needs to have a uniform template and content throughout the project. Model report document should be easily and quickly readable.

After **freezing** the discipline model it is ready to be shred for referring. Sharing of individual discipline models can in some cases be useful.

Second part of the process is **forming a total compatible model**. Architecture BIM coordinator gathers all combined discipline models to a single model. Clash checking is performed.

Clash checking results are presented in **co-operation meeting**. In co-operation meeting the solutions for clashes are formed. This requires expertise and discipline representative must be able to solve complex clash checking related problems. Co-operation meeting is advisable to be part of a "regular" type of design meeting. This way efficiency increases in the process because the movement of designers reduces.

After the meeting the total model is **shared**. Information of the clashes must be informed to the right personnel. Commenting tools in the software were found as a useful way to communicate clashes in the case project.

Presented process was the first of three model compiling processes. Next suggested process is 'bottle neck' discipline co-operation process.

'Bottle neck' discipline co-operation process

Analytics section of the thesis provided information on the dependencies between disciplines. From this data it can be seen that some disciplines are more referred than others. This means that their success in their quality of the models and their capability to stay in schedule is critical. The whole success of the process depends on those disciplines. These factors make them 'bottle neck' disciplines. Suggested process tries support the success of these 'bottle necks'.

Analytics showed that almost all disciplines relay on the design made by all other disciplines. The disciplines that did not have dependency between them were referring each other through some other models. For example almost all disciplines referred architecture modelling which takes into consideration all other disciplines.

Suggested process begins with the co-operation of the most critical design disciplines and then flows towards the ones, which based on their dependencies, also need co-operation.

Idea behind this process is from the existing processes. These kind of smaller meetings between only two or three disciplines was found very beneficial and value adding for the project in interviews.

Suggested process is as follows:

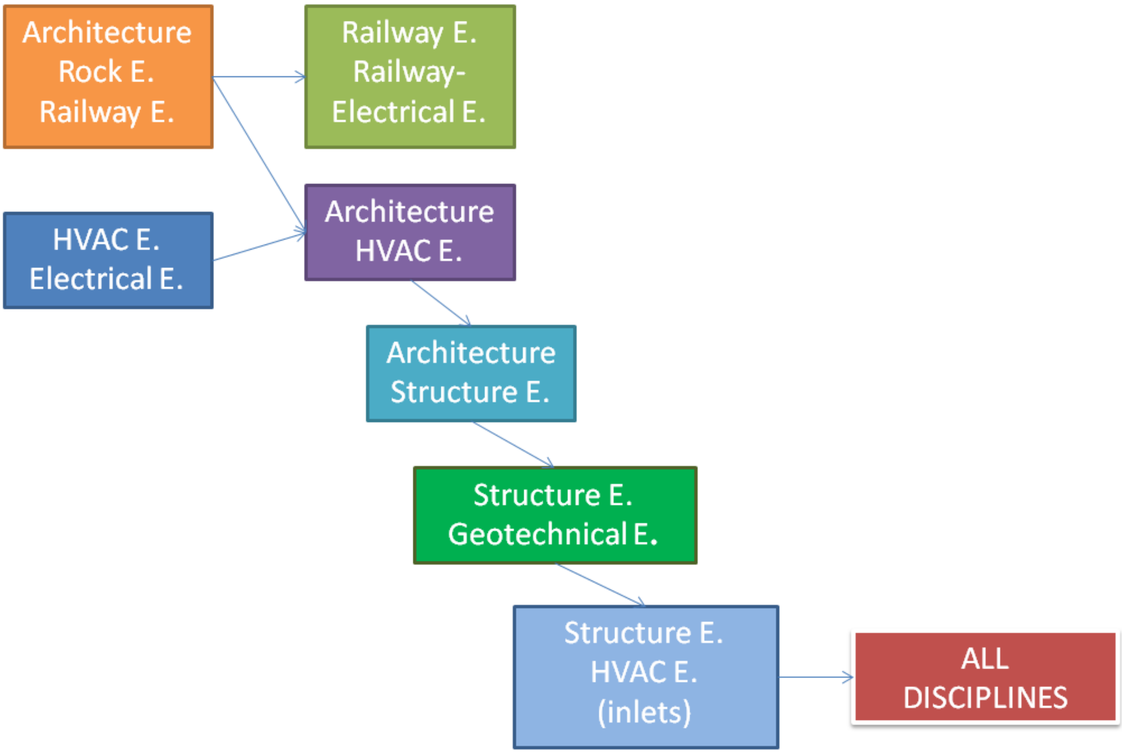


Figure 31 Suggestion for 'bottle neck' discipline process

In the figure shows the co-operation meetings that are needed based on the analytics. In the case project these kinds of meetings were held. The agenda of these meetings is to check two models side by side on two screens and visually inspect them for clashes. In these meetings more accurate results were achieved than in the suggested continuous process.

Thesis suggestion is to further develop this agenda of these meetings. Rather than just inspecting the models in the meetings the solutions could be also worked immediately. Framework for this can be borrowed from knotworking.

Developing design in suggested order can reduce rework in the design process. It also might progress the design faster. Third point for using this process is that by this way the understanding of other disciplines and their way of seeing the design is expected to rise.

Suggested process is advisable to be adapted at an early phase of an design.

This was the second suggested process. In addition to these presented processes a third process to finalize the design in introduced.

Final integration of models

Continuous process for producing compatible models might not give the most accurate and final result. By this I mean that especially in the first design phases the automated clash checking can't be applied for checking the model. Instead of doing that, visual checking needs to be done for the model. If only BIM coordinators are checking the model, it will take a long time. This is why the designer resources should be also taken into checking the models.

One of the design groups in the case project was using this process, when finalizing the design at the end of the set design phase. This process can be used when design is moving to a more accurate level. For example, design is switching from conceptual design to construction design.

The used process was as follows:

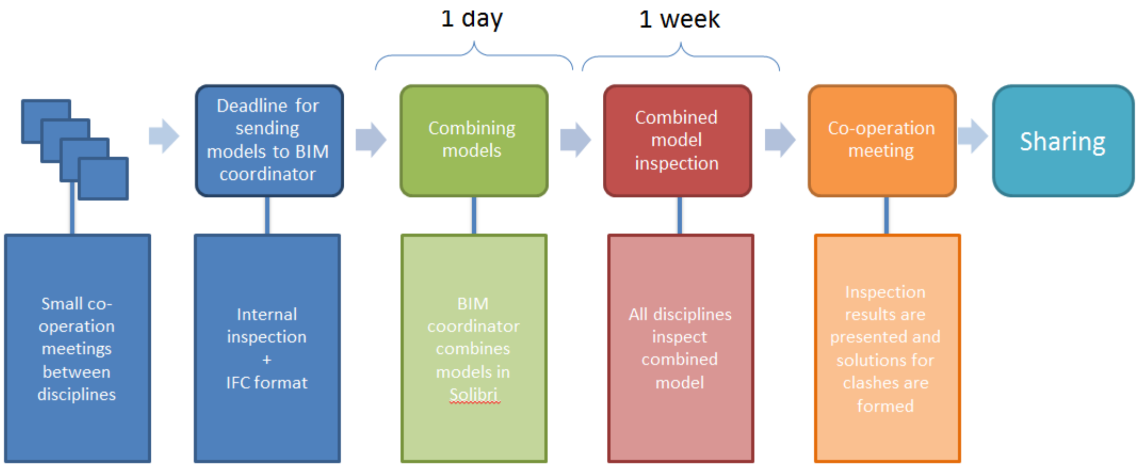


Figure 17 Suggested process for final integration of models

This process increases the resources for checking the model. This process can't be applied to be a continuous process in a project because it is too heavy.

Suggested processes have been now presented. Analyzes section now moves on to present other findings of the thesis.

5.2 Suggested development for design management

This section gives development suggestions for design management in the reference of current state in the case project. Section is divided to categories: technology, process and people. First part covers the learnings from the case project that can be applied to other projects and second part covers the subjects that in the case project needed development. Second part also gives solutions for these case project development suggestions that were found under the research of the thesis.

5.2.1 Learnings from the case project

Described learnings are a result of analytics done in this thesis. They represent the things that were executed well in the case project and from which other projects can learn.

Process

Initial data collecting was performed extremely well in the case project. Based on analytics it was received the highest level of referring in the project. It was also executed in 3D model formats.

2D drawings and 3D models should progress in the same level of detail. Design accuracy in models can be greater than in the drawings. Otherwise the full benefits of BIM are lost.

Combining models frequently results in better quality design.

Restraining **standardized design solutions** early in the design accelerated the progress of overall design.

Producing BIM execution plan with the participating designers resulted in practices that everyone in the project can commit to.

Main needs of information exchange between disciplines are spatial matters. These include geometry, quantity, size, shape, location, and orientation of structures.

When producing models for co-operation, **the level of detail** should be as low as possible. If the models include only the parameters that are needed for referring the usability of models stays high.

People

BIM know how among city authorities made the communication and working with them more efficient.

Technology

In the case project the **client chose to demand BIM based design**. The decision was done even it was known the processes and practices related to that are not at optimum level. Even this being the case, it has proven to be a beneficial decision. The benefits of using BIM based design in a complex project have been unquestionable. Demanding BIM design in the case projects has increased the amount of BIM usage in participating companies in their other projects.

Frequent clash checking and **visualizing design in 3D** has been proved in the case project to add value. Visualizing design has caused such design changes that would have not been noticed from 2D drawings. Managing and understanding the truly complex design solution has been much easier especially because the project is under ground level.

IFC model format currently, even with its limitations, as a best format to collaborate in construction design projects.

Organization

BIM practices are still developing as new tools and possibilities arise. This still causes many practical problems in the daily work of designers. In the case project this was realized. To solve these problems that arises from the daily work in the project, in the case project they had formed a **BIM development group**. In this group the BIM experts of the project had a forum to discuss and solve BIM related problems. They could also spread found good practices to other design groups through this forum. It would be advisable to any project this scale to from this kind of forum.

5.2.2 Development suggestions based on the case project

Following listing covers subjects that the project had underperformed in according to analytics. These matters are suggested to be developed in future of the case project as well as in all future projects.

Process

Communicating and the level of accuracy were found problematic in the case project. It was hard to rely on information when the referrer couldn't be sure if it is accurate or approximation.

Solution: Applying LOD system and status qualification to the process.

Delayed referring information caused **latency** in the design process.

Solution: Mapping dependencies between design tasks. Using characteristics of the Last Planner system provides a systematic way of doing this. Another solution is to define requirements for referred information. Singapore BIM Guideline had great content on how to create these requirements.

In the case project in some cases the **referred material was formatted** to be usable for them by different users. This includes the risk of separate disciplines referring to incompatible material.

Solution: The needs for referred material are defined. **Creator of the original model creates also the co-operated model formats.**

People

Using BIM as tool in some disciplines were on a low level. This caused **latency** in producing good quality models and producing them on time.
Solution: client Procures BIM based design. In the case project it could have been seen to raise the BIM know how and its use a design tools among all project participants. Another solution comes from the development of software. Especially tin the infrastructure engineering side the tools need to improve more to fulfill designer's needs.

Technology

The technology related issues that needed development, according to the case project, are matters that have to wait for the software companies to develop their products better.

Other matters

Construction industry as a whole needs to develop better BIM guidelines for infrastructure engineering.

6 Summary and conclusion

Original purpose of the thesis was to research BIM based design process empirically and to find ways to develop the current state of design processes. This was done through theory research and empirical research.

In the theory part the most useful data was found from the BIM guidelines. In the building industry their level of detail matches the current state of BIM design well. They give good advice in implementing BIM to one's project. Guidelines also gave information on how to organize design processes in BIM based projects. The results of the thesis were based on the processes given in the guidelines. The processes in the guidelines didn't completely fulfill the needs of effective progress of design work. In addition to these empirical data was needed to modify these processes.

In the empirical part of the thesis project meetings were followed and interviews were conducted. These gave insight to useful practices that were used in the case project. They resulted in s developed process model to compatibly produce models and progress design work efficiently.

6.1 Meaning of the thesis

Meaning of the thesis was to develop a process that efficiently produces compatible models. Also its meaning was to develop suggestions for future projects based on the learnings from analytics of the case project.

As the research questions of this thesis imply, the goal was to get insight on the current status of BIM based design work and what is the current used processes of doing BIM based design. The thesis was able to describe the current used processes that were used in the case project.

One meaning was to find out what is done well in the current design work. Interviews gave great insight to this from the personnel that are working with BIM on daily basis. From the interviews the thesis was able to gather a list of suggestions to take into consideration in future projects.

Based on the theory research and the analytics of the thesis, a process for developing design compatibly was developed. This was one of the goals for the thesis as presented in the research questions.

Overall, thesis provided answers to all set research questions.

The only area of the thesis that was unable to fulfill its purpose was the analytics of common data area. Meaning was to develop a design process based on the dependencies between design disciplines. The dependencies turned out to be too complex to be able to apply DSM method. Analytics of the common data area still gave some interesting information of the dependencies between disciplines.

6.2 Achieved results and their use

The thesis achieved four results:

- continuous co-operation process
- ‘bottle neck’ discipline co-operation process
- process for final integration
- a list of suggestions for BIM based design projects.

Usefulness of the results varies. Some may be used in all BIM based projects, while others in projects similar to the case project.

Continuous co-operation process and process for final integration can be and should be used in every BIM based design project. They are based on the guideline research and the used processes in the case project. These are most useful in a BIM project involving many different disciplines and designers.

´Bottle neck’ discipline co-operation process can be used in similar projects as the case project. It is based on the disciplines that are involved in the case project and it is a solution for a specific case. Similar mapping of ‘bottle neck’ disciplines should be done in every project and then form a process on how to deal with these ‘bottle necks’.

Development suggestions listed in the thesis can be applied to any BIM based project. They are in very general form even though they give solutions to specific problems. A good read for a BIM project planner could also be the results of interviews in this thesis. They raise a lot of practical issues that the designers face in every day work with BIM

Some results were also discovered outside what was planned. These include the results in the interviews. The interviews result shows the benefits of using BIM as a tool in design at some extent. Results also give insight on some of the problems that still are related to BIM based design.

6.3 Achieved new findings

All the processes developed in this thesis are new findings. They give solutions for the current state of BIM based designing. The processes are based on the ones in the guidelines but then modified with the practical experiences.

Thesis shows that a design project can be executed with BIM tools. It even suggests that there are benefits for using BIM in a large scale projects like the project case. Using BIM as a tool for a design still requires management and new kind of practices.

So the achieved new findings in this thesis were:

- continuous co-operation process
- ‘bottle neck’ discipline co-operation process
- process for final integration
- a list of suggestions for BIM based design projects.
- BIM benefits
- current state practical problems in BIM based design and co-operation
- current state of practices of using BIM

6.4 Valuating the results

Achieved results in thesis are solutions for the current state of the design done in projects. They improve the efficiency of the design process. By using these achieved results the management of design is clear and more easily executed.

As said, results provide solutions for the current state. This means that when the BIM tools develop the results of this thesis will become outdated.

In the current state of the design these kind of suggested model updating cycles are needed in the design process. This is a cause of one not being able to design in real time due to compatibility issues of the software. Hopefully in the future the programs will communicate better with each other and make the real time designing possible. At this stage where these model updating cycles are not needed the results of the thesis will be outdated.

Maybe in the future, the practices for level of detail and for the status of models have been standardized. At this point they will not need as much attention as the results of the thesis suggest. Hopefully these matters are developed in an industry level and they don't need to be completely re-planned in each project.

The thesis will not bring a new revolution to the construction industry. But the presented results will ease the co-operation between design disciplines that are working together in BIM based design projects.

Results are not also something final. They need to be implemented to the everyday work of designers and to be developed further.

6.5 Suggestions of possible new research directions

Based on the thesis, BIM guidelines for infrastructure engineering are behind the ones of building engineering. BIM guidelines for infrastructure engineering would need more development and better accuracy. BIM co-operation in projects that include both of these were not handled in the guidelines. These need to be developed.

As time passes by, results of the thesis will outdate. New process for compatible model producing should then be developed.

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Dependencies matrix

Dependency

UPLOADS/DOWNLOADS	Structural Engineering 2	Street and Traffic Planning	Structural Engineering 1	Rock and geo engineering 1 and structural engineering 1	Helsinki City Planning Department	Rock Engineering 2 and 3	Architect 3	Geo Engineering 2 and 3	Source Information Engineering	HVAC, Water and Electrical 1 Engineering	Track Engineering	Developer and Project Management Consultant	Architect 1	BIM Responsible Architect 2	Project Bank Service Provider and BIM Consulting	Architect 2	BIM Responsible Architect 1	Fire Safety Engineering	Electric Track Engineering	Ground Water Consultant	sakko.fi	(blank)	Electrical Engineering 2 and Automation Engineering	Project Management Sub Consultant	Electrical and Automation Engineering	Finnish Transport Agency	Radio Network Planning	Acoustics Engineering	BIM Consultant	Rock Stress Consultant	BIM Responsible Structural Engineering 2	Cost Analyst	Communications Consultant	Traffic Planning	Railway Safety Planning	Landscape Architect	Energy Consultant	PM Subconsultant	Bridge Engineering	3rd party Fire Safety Consultant	helen.fi	Grand Total
1. Source information engineering	9682	166	891	862	137	221	305	996	102	139	289	202	235	298	211	45	509	23	76	54	7	2	15	71	11	16	66	3	5	9	9		1	17	4		1		6			15686
2. Rock and geo engineering 1 and structural engineering 1	556	2804	516	1128	1093	169	94	205	756	124	448	177	447	6	175	20	45	16	14	20	2	167	8	20	1	14	49	27	27	1		18	7	2			2					9158
3. Rock Engineering 2 and 3	484	834	779	138	1089	474	513	215	702	81	113	91	4	65	61	230		15	55	216	124	50	11	7		6	1	11		150	12	5		1								6537
#N/A	639	829	418	725	539	249	387	183	251	279	298	219	198	51	76	45	13	109	73	34	25	48	50	44	27	31	33	21	10	7	5	9	21	6	8		1					5961
4. Geo Engineering 2 and 3	560	1317	344	363	135	744	382	215	447	16	33	13		78	32	101		2	1	191	54	32		42	2	2	1	19	22	1	6	41		1								5197
5. Architect 3	117	814	618	156	316	466	83	243	23	318	145	206	53	46	23	60		168	25	4	20	25	77	5	1	14	17	66	24	1		40	1	18		13		1				4207
6. Track Engineering	68	350	373	436	150	245	299	107	167	240	257	99	141	83	81	82	28	47	158	1	1	13	8	16		13	11	8	2	2	50	6		3	1		5	1				3552
7. Structural Engineering 1	90	484	163	210	214	20	275	291	98	26	173	61	6		32		1	2	8	2		39	25	11		19	18	1	18		1	4		1								2293
8. BIM Responsible Architect 2	136	133	8	32	154	107	38	77	20	175	45	76	8	13	13	57	5	78	6		93	6	6	1	145	17		12	10	4	47	11	1	1				2				1537
9. Structural Engineering 2	60	269	202	73	143	82	13	55	4	18	11	5		191	1	40	1	2	1		102	1	1	34			1	5			12	1							6			1334
10. Architect 1	11	145	30	166	158	1	28	2	7	216	68	86	70	38	3	19	20	39	2			16	6	3	1	11	4	12	1			3	1					14				1181
11. Developer and Project Management Consultant	188	48	53	52	16	79	108	44	13	38	7	95	25	23	1	32	1	17	26		4	2	28	16	30	33	4	2	2		6			1	7			6			1	1008
12. Project Bank Service Provider and BIM Consulting	83	82	78	117	128	20	43	34	25	24	7	52	38	13	15	2	3	10	91		7			8	8	16	4	4	3		2	1										918
13. Street and Traffic Planning	49	243	10	8	60		52	19	2		135	13	45	3		1			4	1	8	2	1					11						23		14		1				705
14. Architect 2	52	110	19	19	94	47	32	15	20	85	15	72	7	4	3	14		19	2		20		6	1	9	15		17										2				699
15. Helsinki City Planning Department	214	1		37	3	26	2	75	35	2		3		175	1	11		1			8			3	2	6						2										607
16. HVAC, Water and Electrical 1 Engineering	22	13	48	43	40	1	54	1		77	6	37	2	4	23		10	1	1			10	14	1		2	2	1	15		7											435
17. BIM Responsible Architect 1	4	37	9	77	27	4	6			106	4	20	4	3	16		6	13	1			12	1			1			22			1										374
18. Acoustics Engineering	56	30	64	11	52	39	48	1	24	6	1	9	4					1						1		2	6	5														360
19. Electric Track Engineering	9	20	62	27	18	13	20	4	2	19	9	3	17	1	12	8		11	37				1		3	2	12								5		19					334
20. Fire Safety Engineering	14	11	33	9	26	6	23	2	2	59	9	30	17	4		5		39	4				3			7	5								8					8		324
21. Electrical Engineering 2 and Automation Engineering	33	62	50	11			20		3	20	1	1	4	2	39	3	5						4	4	2		5				2			1								272
22. BIM Responsible Structural Engineering 2	20	25	29	11	16	14		8		11		12		20	15							7			3				15			4										210
23. Railway Safety Planning	106	12	2	9		3	3	2		4	1	2	6			1			3				23	3		2																182
24. Project Management Sub Consultant	5	3	10	17		1	13	4		5		3	5					1					9	3		1									3							83
25. Communications Consultant					10							4										2				13							51									80
26. Traffic Planning	8	14	4		10	1	4	2				4												1										1		3						52
27. Ground Water Consultant		4	7	2	6	9	6	3	8	1	1	1												1																		49
28. Electrical and Automation Engineering														10											8						8											26
29. Radio Network Planning			16									2	5														2															25
#NAME?	2		1							1					2																	1										7
30. Finnish Transport Agency					2							2														1							2									7
Grand Total	13268	8860	4837	4739	4636	3041	2851	2803	2711	2090	2076	1600	1341	1131	835	776	647	614	588	523	475	434	297	296	253	244	241	225	176	175	167	147	85	76	36	30	28	27	12	8	1	63400

LEGEND

(red)	TOP 30
(light red)	TOP 100

Dependency matrix without source information engineering and match errors

Dependency

UPLOADS/DOWNLOADS	Structural Engineering 2	Street and Traffic Planning	Structural Engineering 1	Rock and geo engineering 1 and structural engineering 1	Helsinki City Planning Department	Rock Engineering 2 and 3	Architect 3	Geo Engingeering 2 and 3	HVAC, Water and Electrical 1 Engineering	Track Engineering	Developer and Poject Management Consultant	Architect 1	BIM Responsible Architect 2	Project Bank Service Provider and BIM Consulting	Architect 1	BIM Responsible Architect 1	Fire Safety Engineering	Electric Track Engineering	Ground Water Consultant	sakko.fi	(blank)	Electrical Engineering 2 and Automation Engineering	Project Management Sub Consultant	Electrical and Automation Engineering	Finnish Transport Agency	Radio Network Planning	Acoustics Engineering	BIM Consultant	Rock Stress Consultant	BIM Responsible Structural Engineering 2	Cost Analyst	Communications Consultant	Trafic Planning	Railway Safety Planning	Landscape Architect	Energy Consultant	PM Subconsultant	Bridge Engineering	3rd party Fire Safety Consultant	helen.fi	Grand Total			
2. Rock and geo engineering 1 and structural engineering 1, BIM responsible Architect 3	556	2804	516	1128	1093	169	94	205	124	448	177	447	6	175	20	45	16	14	20	2	167	8	20	1	14	49	27	27	1		18	7	2			2					9158	9158	21,94 %	1
3. Rock Engineering 2 and 3	484	834	779	138	1089	474	513	215	81	113	91	4	65	61	230		15	55	216	124	50	11	7		6	1	11		150	12	5		1								6537	15695	37,60 %	2
4. Geo Engineering 2 and 3	560	1317	344	363	135	744	382	215	16	33	13		78	32	101		2	1	191	54	32		42	2	2	1	19	22	1	6	41		1								5197	20892	50,05 %	3
5. Architect 3	117	814	618	156	316	466	83	243	318	145	206	53	46	23	60		168	25	4	20	25	77	5	1	14	17	66	24	1		40	1	18		13		1				4207	25099	60,12 %	4
6. Track Engineering	68	350	373	436	150	245	299	107	240	257	99	141	83	81	82	28	47	158	1	1	13	8	16		13	11	8	2	2	50	6		3	1		5	1				3552	28651	68,63 %	5
7. Structural Engineering 1	90	484	163	210	214	20	275	291	26	173	61	6		32		1	2	8	2		39	25	11		19	18	1	18		1	4		1								2293	30944	74,12 %	6
8. BIM Responsible Architect 2	136	133	8	32	154	107	38	77	175	45	76	8	13	13	57	5	78	6		93	6	6	1	145	17		12	10	4	47	11	1	1				2				1537	32481	77,81 %	7
9. Structural Engineering 2	60	269	202	73	143	82	13	55	18	11	5		191	1	40	1	2	1		102	1	1	34			1	5			12	1							6			1334	33815	81,00 %	8
10. Architect 1	11	145	30	166	158	1	28	2	216	68	86	70	38	3	19	20	39	2			16	6	3	1	11	4	12	1			3	1					14				1181	34996	83,83 %	9
11. Developer and Poject Management Consultant	188	48	53	52	16	79	108	44	38	7	95	25	23	1	32	1	17	26		4	2	28	16	30	33	4	2	2		6			1	7			6			1	1008	36004	86,25 %	10
12. Project Bank Service Provider and BIM Consulting	83	82	78	117	128	20	43	34	24	7	52	38	13	15	2	3	10	91		7			8	8	16	4	4	3		2	1										918	36922	88,44 %	11
13. Street and Traffic Planning	49	243	10	8	60		52	19		135	13	45	3		1			4	1	8	2	1					11						23		14		1				705	37627	90,13 %	12
14. Architect 1	52	110	19	19	94	47	32	15	85	15	72	7	4	3	14		19	2		20		6	1	9	15		17										2				699	38326	91,81 %	13
15. Helsinki City Planning Department	214	1		37	3	26	2	75	2		3		175	1	11		1			8			3	2	6						2										607	38933	93,26 %	14
16. HVAC, Water and Electrical 1 Engineering	22	13	48	43	40	1	54	1	77	6	37	2	4	23		10	1	1			10	14	1		2	2	1	15		7											435	39368	94,30 %	15
17. BIM Responsible Architect 1	4	37	9	77	27	4	6		106	4	20	4	3	16		6	13	1			12	1			1			22			1										374	39742	95,20 %	16
18. Acoustics Engineering	56	30	64	11	52	39	48	1	6	1	9	4					1						1		2	6	5														360	40102	96,06 %	17
19. Electric Track Engineering	9	20	62	27	18	13	20	4	19	9	3	17	1	12	8		11	37				1		3	2	12								5		19					334	40436	96,86 %	18
20. Fire Safety Engineering	14	11	33	9	26	6	23	2	59	9	30	17	4		5		39	4				3			7	5								8					8		324	40760	97,64 %	19
21. Electrical Engineering 2 and Automation Engineering	33	62	50	11			20		20	1	1	4	2	39	3	5						4	4	2		5				2			1								272	41032	98,29 %	20
22. BIM Responsible Structural Engineering 2	20	25	29	11	16	14		8	11		12		20	15							7			3				15			4										210	41242	98,79 %	21
23. Railway Safety Planning	106	12	2	9		3	3	2	4	1	2	6			1			3				23	3		2																182	41424	99,23 %	22
24. Project Management Sub Consultant	5	3	10	17		1	13	4	5		3	5					1					9	3		1									3							83	41507	99,43 %	23
25. Communications Consultant					10						4										2				13							51									80	41587	99,62 %	24
26. Traffic Planning	8	14	4		10	1	4	2			4												1										1		3						52	41639	99,74 %	25
27. Ground Water Consultant		4	7	2	6	9	6	3	1	1	1												1																		49	41688	99,86 %	26
28. Electrical and Automation Engineering													10											8						8											26	41714	99,92 %	27
29. Radio Network Planning			16								2	5														2															25	41739	99,98 %	28
30. Finnish Transport Agency					2						2														1							2									7	41746	100,00 %	29
Grand Total	13268	8860	4837	4739	4636	3041	2851	2803	2090	2076	1600	1341	1131	835	776	647	614	588	523	475	434	297	296	253	244	241	225	176	175	167	147	85	76	36	30	28	27	12	8	1	41746			

Example1 of original data, downloads

Nr.	Date	Time	User	Company	Downloaded file (no spaces)
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2	20.8.2014	13:02:37	[redacted]	[redacted]	KR_1700_201_SR_7680_8080.pdf
3	20.8.2014	13:02:37	[redacted]	[redacted]	KR_1700_202_SR_8060_8460.pdf
4	20.8.2014	13:09:42	[redacted]	[redacted]	PISARA_yhteystiedot.pdf
5	20.8.2014	13:31:26	[redacted]	[redacted]	AR_T001_003_HAK.pdf
6	20.8.2014	13:35:07	[redacted]	[redacted]	LI_009_015_HAK.pdf
7	20.8.2014	13:36:14	[redacted]	[redacted]	KK_2000_010_HAK.pdf
8	20.8.2014	13:42:02	[redacted]	[redacted]	LAATU_Liite4_7_NUMOHJE.pdf
9	20.8.2014	13:45:23	[redacted]	[redacted]	RA_T115_005_HAK.pdf
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20	20.8.2014	14:26:42	[redacted]	[redacted]	GE_1600_003_TOO.pdf
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Example2 of original data, uploads

		Viimeisimmän revisiontallentaja			Uniikki tiedoston ID		Tiedostonnimi			Revisio (vapaa tekstikenttä)	Lohko	Dokumenttityyppi	Karttalehti (lähtöaineisto)	Sisältö (vapaa tekstikenttä)	Alaryhmä	Pääryhmä			Muokattu	Omistaja	Aikaleima						Suunnittelusta		
Removed	Sum	Curren	Curre	Statu	Md5	Folder	ClientFile	Keyw	Note	UserF	Segm	IdFile	MapS	Cont	IdSub	IdMai	IdTyp	IdCor	Modif	Owner	TimeStamp	Id	IdDoc	Creat	Draw	IdCor	IdDe	IdDra	Po
\N	891c5045318ad6423883e8c7	antti.miet	2	1	d41d8cc	Q	Vauhtitie_MUOKATTU.dgn	\N	\N	\N	\N	\N		Suunnit	39	6	1	\N	2013-11-	[redacted]	26.11.2013 12:56	84	22639	2013-11-	\N	\N	\N	\N	\N
\N	8b61c893936fd29aea2a5b2d	antti.miet	2	1	d41d8cc	Q	Vauhtitie_MUOKATTU.dwg	\N	\N	\N	\N	\N		Suunnit	39	6	1	\N	2013-11-	[redacted]	26.11.2013 12:56	85	22640	2013-11-	\N	\N	\N	\N	\N
\N	872e40eae7626d83a37189d9	antti.miet	1	1	79123db	D	I8006-033-08.pdf	\N	\N	\N	\N	\N	673497	Rakenn	13	3	1	\N	\N	[redacted]	26.11.2013 13:24	152	2960	2013-11-	\N	\N	\N	\N	\N
\N	b00568fb3bcb9c5cedbbe426	antti.miet	1	1	e66e64	R	V8006-087-08.pdf	\N	\N	\N	\N	\N	673497	Rakenn	13	3	1	\N	\N	[redacted]	26.11.2013 13:24	206	3014	2013-11-	\N	\N	\N	\N	\N
\N	2a63113ad6a750703ed309f53	antti.miet	1	1	652043	C	R8005-450-08.pdf	\N	\N	\N	\N	\N	673497	Rakenn	13	3	1	\N	\N	[redacted]	26.11.2013 13:24	232	3100	2013-11-	\N	\N	\N	\N	\N
\N	1bd662b6a37bb35304daa53b	antti.miet	1	1	b2b2ad	O	P76-053205.pdf	\N	\N	\N	\N	\N	674496;	Rakenn	13	3	1	\N	\N	[redacted]	26.11.2013 13:53	443	8575	2013-11-	\N	\N	\N	\N	\N
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\N	d0d142c62da7ce97638b9e44	antti.miet	2	1	d41d8cc	Q	R8005-471-08.pdf	\N	\N	\N	\N	\N		Rakenn	304	3	1	\N	2013-11-	[redacted]	3.1.2014 13:00	965	3121	2013-11-	\N	\N	\N	\N	\N
\N	9d291600fea9f2eecaa9fcef72	antti.miet	2	1	d41d8cc	Q	R8005-533-08.pdf	\N	\N	\N	\N	\N		Rakenn	304	3	1	\N	2013-11-	[redacted]	3.1.2014 13:00	1027	3183	2013-11-	\N	\N	\N	\N	\N
\N	1e4ec4901786e55887256d3cf	antti.miet	1	1	6e19fea	C	P4788-055-04.pdf	\N	\N	\N	\N	\N	672495,	Rakenn	304	3	1	\N	\N	[redacted]	10.1.2014 11:15	1787	7841	2013-11-	\N	\N	\N	\N	\N
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\N	61f7711de688cefae257fa8eed	antti.miet	1	1	a32d6c	N	R82-030742.pdf	\N	\N	\N	\N	\N	674496;	Rakenn	304	3	1	\N	\N	[redacted]	10.1.2014 12:47	1993	8648	2013-11-	\N	\N	\N	\N	\N
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\N	5ad3069276eab5ffe8dab2a41	antti.miet	1	1	b80f4ff4	O	I8075-339-09.pdf	\N	\N	\N	\N	\N	674496;	Rakenn	304	3	1	\N	\N	[redacted]	10.1.2014 12:55	2294	11028	2013-11-	\N	\N	\N	\N	\N
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\N	57d22b88e7a326429a500bd	perttu.va	2	1	9f59a47	F	131213_Liite2_Pisara_Nimio.dwg	\N	\N	\N	\N	\N	\N	NimiÃ¶m	715	7	3	\N	2013-12-	[redacted]	4.2.2014 13:16	2856	25233	2013-12-	\N	\N	\N	\N	\N
\N	65799d85450e93387c51419c	hannele.	1	1	24befcd	Y	LAATU_Liite4_6_4_TIETOMALLISEL.xlsx	\N	\N	\N	\N	9	\N	LaatujÃ	714	7	3	\N	\N	[redacted]	20.3.2014 10:49	3168	25522	2014-02	\N	\N	\N	\N	\N
\N	34267556ae27733c0237201d	tomi.tular	16	1	9dec124	F	AR_009_001_KES.pdf.pdf	\N	\N		KES	12	\N	KESKU:	\N	\N	2	\N	2014-05	[redacted]	9.5.2014 10:06	3469	28413	2014-04	\N	\N	2	\N	\N
\N	fb93c4e5108a09fe195ac1ea21	antti.miet	1	1	345d41c	Z	vesi_672494x2.dgn	\N	\N	\N	\N	\N	672494;	Vesi ja v	301	3	1	\N	\N	[redacted]	14.5.2014 6:36	3543	4219	2013-11-	\N	\N	\N	\N	\N
\N	d55314258ff4f78de69aedc051	antti.miet	1	1	6d3d80	C	kanta_674494.dgn	\N	\N	\N	\N	\N	674494	Kantaka	402	4	1	\N	\N	[redacted]	15.5.2014 9:00	3569	22248	2013-11-	\N	\N	\N	\N	\N
\N	231df20a3385825e2af74e7a1	antti.miet	1	1	8c2b69	E	kanta_673496_3D.dgn	\N	\N	\N	\N	\N	673496	Kantaka	402	4	1	\N	\N	[redacted]	15.5.2014 9:11	3581	22266	######	\N	\N	\N	\N	\N

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