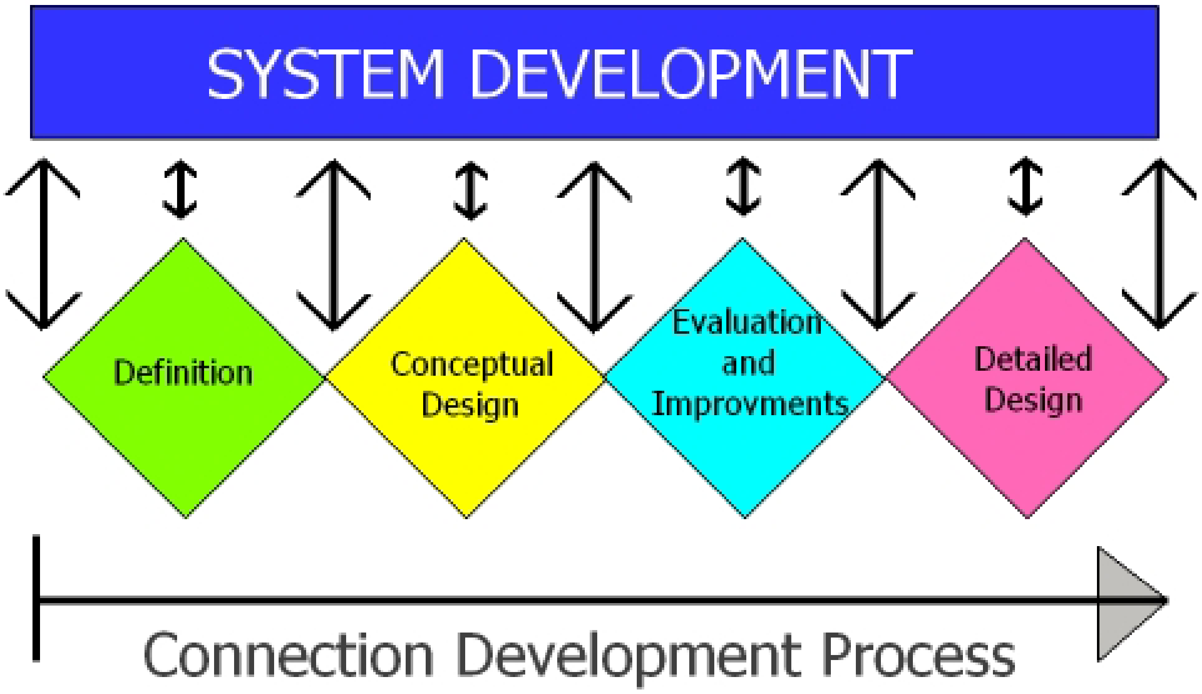

Product Development in the Building Industry Based on Industrial Thinking

Method for Connection Design

Master's Thesis in the Programme Structural Engineering

CARL JANSSON

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Department of Civil and Environmental Engineering
Division of Structural Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
The four activities in the connection development method. Each activity is illustrated as a rhombus. Information between the system development and the connection development is illustrated as arrows.

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ABSTRACT

The need for new buildings in combination with higher competition and quality requirements forces the building industry to be more effective. In order to achieve this, the building industry has started to think industrially, by using well-planned and optimised processes with inspiration from traditional manufacturing industry. Prefabrication action is a good example of when building industry is utilizing industrial thinking. Prefabrication involves manufacturing of elements in factory and assembly on-site. In order to achieve effective erection of the houses, the structural connections must be developed to allow easy assembly.

The aim of this Master's project was to investigate how the development process of structural connections should be carried out, with including activities and how and which information that should be communicated during the process.

The investigation has resulted in a method that should aid designers during the development process of connections. The connection development method uses ideas from traditional product development, used in manufacturing industry. The method suggests four clearly defined activities that should be included in a connection development process, *Definition, Conceptual design, Evaluation and improvements* and finally *Detailed design*. The *Definition* activity should give the structure of the development process, stating how information should be treated by suggesting standard document formats, etc. The *Conceptual design* activity should result in a few connection concepts that should be evaluated in the *Evaluation and improvement* activity, which should deliver one connection concept to the *Detailed design* activity. The *Detailed design* should make the connection ready for manufacturing. The activities should be iterative. The process is however not iterative between the activities, the activities end with a clearly articulated breakpoint. The activity's aim should be confirmed before the next activity is initiated. To a high degree, the new knowledge in this work consist of that the intuitive and creative activities are explicitly defined. The method was confirmed with help of a case study. The development process of an existing building system's connections where simulated in the case study.

In the case study, it is concluded that predefined requirements and demands on the connections are more or less impossible to include in the method, due to the fact that there exists so many different types and situations. It is therefore better to use non-static documents that should be completed during the development process as new information about the system is known. The set up of the document should be adjusted for each development process.

Key words: industrial construction, industrial thinking, product development, structural connection, guidelines, method for connection development

Produktutveckling i byggindustrin baserad på industriellt tänkande
Metod för anslutningsutformning
Examensarbete inom konstruktionsteknik
CARL JANSSON & SVEN TÄGTSTEN
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SAMMANFATTNING

Behovet av nya byggnader i kombination med ökad konkurrens och högre kvalitetskrav tvingar byggindustrin att bli mer effektiv. För att möta dessa krav har byggindustrin börjat tänka industriellt, genom att använda sig av väl genomtänkta och optimerade processer med inspiration från traditionell tillverkningsindustri. Ett bra exempel på när byggindustrin tillämpar industriellt tänkande är prefabricering av byggnadselement. För att kunna ha ett snabbt uppförande av byggnaderna måste anslutningarna hos elementen vara utvecklade för att tillåta en snabb montering.

Målet med detta examensarbete är att utreda hur utvecklingsprocessen för dessa anslutningar ska utföras på ett effektivt sätt. De ingående delaktiviteterna samt informationshantering ska utredas och definieras.

Utredningen har resulterat i en metod som ska hjälpa konstruktörer under utvecklingsprocessen av anslutningar. Metoden är baserad på teori från traditionell produktutveckling som används i tillverkningsindustrin. I metoden föreslås det att fyra tydligt definierade aktiviteter ska användas i utvecklingsprocessen, *Definition, Konceptuell utformning, Utvärdering och förbättring* och slutligen *Detaljerad utformning. Definitions*-aktiviteten ska klargöra strukturen för utvecklingsprocessen, bestämma hur information ska kommuniceras genom att föreslå standarddokument etc. Den *Konceptuella utformningen* ska resultera i att ett antal anslutningskoncept levereras till *Utvärdering och förbättrings*-aktiviteten där ett anslutningskoncept ska väljas och levereras till *Detaljerad utformnings*-aktiviteten. *Detaljerad utformnings-aktiviteten* ska göra anslutningskonceptet färdigt för tillverkning. En aktivitet ska avslutas med en tydlig brytpunkt där det säkerställs att målet med aktiviteten är uppfyllt. Processen ska därmed inte behöva vara iterativ mellan aktiviteterna, metoden ar uppbyggd så att godkännandet av en aktivitet är irreversibelt. Nyhetsvärdet i arbetet ligger i hög grad i att det sätter ord på aktiviteter i det intuitiva och kreativa utvecklingsskedet samt att processen är linjär och irreversibel. Metoden har bekräftats med en fallstudie där utvecklingsprocessen av ett befintligt byggsystems anslutningar simulerades.

Under fallstudien upptäcktes det att fördefinierade krav på anslutningarna i princip är omöjliga att inkludera i metoden eftersom det ska täcka alla tänkbara anslutningstyper och fall. Det är därför bättre att använda sig av icke-statiska dokument som kompletteras med krav och information under projektets gång, allteftersom information om och från systemet blir känt. Konfigurationen av de icke-statiska dokumenten ska anpassas till respektive utvecklingsprocess.

Nyckelord: Industriellt byggande, industriellt tänkande, produktutveckling, lastöverförande anslutning, riktlinjer, metod för anslutningsutveckling

Contents

Preface

This Master's project was carried out at NCC Teknik, Sweden, and at the Division of Structural Engineering at Chalmers University of Technology, Sweden, during the summer and autumn of 2007.

We would like to thank our supervisors at NCC Teknik, Dr Jonas Magnusson and Adj. Prof. Dan Engström for their help and support during the project. They have helped and encouraged our work during the whole process. We would also like to thank our supervisor and examiner at Chalmers Dr. Marie Johansson at the Department of Civil and Environmental Engineering, for her help and support during the project. Further on, we would like to thank the rest of the staff at NCC Teknik for providing us an inspiring working climate. We would also like to thank Mr Sakari Sipilä at Consolis for providing material to the case study.

We have performed our work in a small office room together with other students. Therefore, thanks to Gustav Deuschl, Rickard Caster, Erik Jürisoo and Robert Staaf for a good working atmosphere. Erik and Robert have also been our opponents and they have helped us during the project. So, extra thanks to them for the valuable feedback they have given us.

We would also like to thank our girlfriends Anna and Therese and our families for their support.

Göteborg, December 2007

Carl Jansson & Sven Tägtsten

1 Introduction

This Master's project addresses the development process regarding connections during the development of an industrial building system. The word connection is here defined as the interface between elements such as walls, beams and floors.

1.1 Industrial thinking and industrial construction

The need for new buildings in combination with higher competition and quality requirements forces the construction industry to be more effective. Therefore, building industry has started to think industrial; to gain benefits with well thought-out and optimised processes. The processes will be repeated in the same way as in traditional manufacturing industry.

One way for building industry to use industrial thinking is to prefabricate elements in a factory and assemble them on the building site, which is called prefabrication action. In prefabrication action a product is firstly developed – the building system. Houses are then developed and built within the system, in the form of building projects.

There exists several definitions of industrial construction, a definition that comply to the aim and purpose of this Master's project is originally written by Lessing et al (2005) and translated by Lassl and Löfgren (2006). “Industrial construction refers to an integrated manufacturing and construction process with a well-designed organisation which comprises effective steering, preparation and control of resources, activities and results with the help of highly refined components”. This definition could be rewritten to agree more with industrial thinking, where the focus is on the way of thinking and not on the integrated manufacturing and construction process. The definition could then be written as: ”Industrial thinking refers to a working procedure that makes use of a well designed organisation which comprises effective steering, preparation and control of resources, activities and results”.

In traditional building production the construction work is mainly performed on-site. Work on-site often results in longer construction time. Quality is harder to assure in traditional on-site production since the product is dependent on for example weather and individual labour skills. It is therefore beneficial to produce building components in factories and assemble them on-site. Quality and an effective use of resources can more easily be assured in a factory production. The most favourable case, which requires that prefabrication action is utilized to its maximum, is when the work on site only consists of assembly. In reality, supplementary work is always needed in different extent, depending on the degree of industrialisation. One can say that the time on site decreases with a higher degree of industrialisation. Furthermore, it is of great importance that all working operations are well considered and optimised regarding time, economy and quality aspects, which is the essence of industrial thinking. Since the time on-site is crucial and mainly consists of assembly of the prefabricated elements, the incentive of having convenient connections is therefore great.

Industrial construction can be divided into two stages; *the product development stage*, where the building system itself is developed and the *project development stage* where the system is adjusted to a certain project, e.g. a building. In the product development stage the building systems restrictions are set, what type of houses, which customers it is aimed for etc. Industrial thinking should of course be applied from the very beginning in the product development stage. The way of thinking should also be used when developing components within the system.

1.1.1 History

During the post-war era the immediate need for housing and the lack of skilled labour in Europe forced the building industry to develop new and more rationalised building processes. The solution for how to produce houses in a great extent for a low cost was to industrialise and standardise the building systems. This industrialisation reduced the construction time on site and made the buildings easier to assemble. To gain economical benefits larger quantities had to be produced, which lead to decreased number of possible architectural and material options (Adler, 2005). Concrete was often the chosen material in the elements, thanks to its relatively low cost, good structural performance and durable surface when used as façade elements. In other words the flexibility of the systems was very restricted. Significant for these houses are that they were often high-rise buildings constructed of prefabricated concrete elements with visible joints (Lassl and Lövgren, 2006). A typical house with prefabricated elements from the post-war era is shown in Figure 1.1.

Figure 1.1 Typical house with prefabricated elements and visible joints from the post-war era.

The result of this mass housing was not positive from all point of views, even though the progression in technology development and the knowledge in the industrial building process were satisfactory. The systems did not listen to new requirements and demands, from the world around that was changing. The systems only changed due to improved technology that aimed to make the system more efficient, i.e. requirements set by the system itself. Architectural and user friendly options where not applied in a big extend. (Adler, 2005)

The size of the buildings led to the fact that the tenants had problems to relate themselves to the big complexes, and the feeling of being an individual where, in a sense, lost. The buildings have also been criticised for their lack of architectural quality, being impersonal and not adjusted to fit the customers' needs, e.g. the flats' planning were restricted, though the most of the walls were load bearing and not moveable. The interior, such as kitchens and bathrooms, were also standardised and not possible to influence by the tenants. Together all of these factors led to that, when the most urgent housing need had decreased, the ones who could afford moved to other areas. Only the poorest stayed and many areas slowly became slum (Power, 1997).

Due to this mass housing, and its social effects, industrial construction has a bad reputation among people. As a reaction to this, the most of the houses erected during the 70's and 80's were once again in-situ constructed. The houses became more expensive since all benefits of mass production were lost. When the houses became too expensive in the 90's the building-industry had to find new methods to rationalise the building process and once again industrial construction gained interest, this time with the knowledge acquired from earlier mistakes.

1.1.2 Building systems – open and closed

Current industrial construction has developed far from post-war mass housing. Today a customer can choose between several architectural and design options when buying a house from a manufacturer. However, each company has its own building system and the systems are more or less closed in the meaning that all components are manufactured or designed by the same company; a system is only compatible within its own limits and is not connectable with other systems.

Unlike in a closed system, it would in an open system be possible for different actors to develop components that fit the system. The benefits with such a system are e.g. increased flexibility for customers and increased competition between sub contractors. This stimulates the building industry to more cost and time effective solutions since more actors can produce components to the system (Lassl and Löfgren, 2006). Further on, more involved persons or companies may be beneficial in an innovative point of view.

When developing a product in an open system (i.e. the building system itself) two approaches are possible (Lassl and Löfgren, 2006):

Design based approach: The system owner "invents" the components and delivers drawings to a subcontractor, who should produce the components. This approach does demand less communication between the system owner and the manufacturer since the system owner treats the development of the connections.

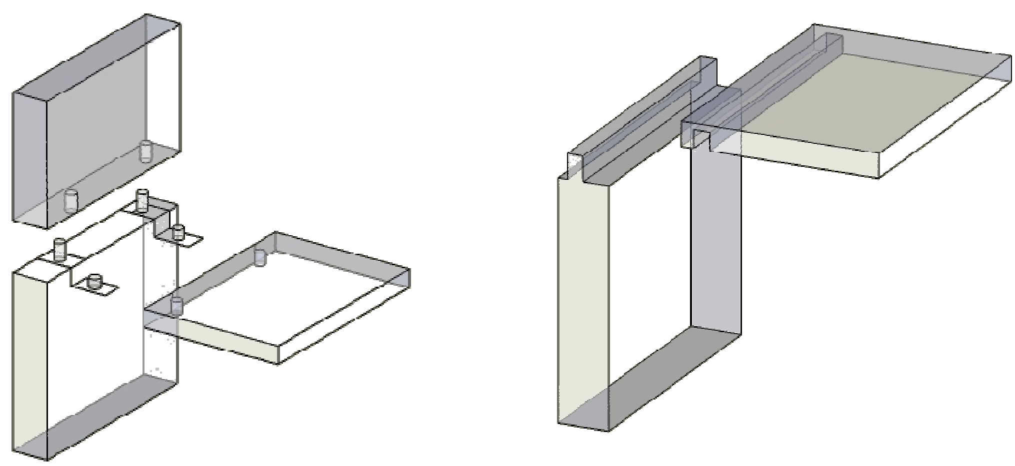
Function based approach: The system owner specifies the demands on a certain component and different actors involved in the system are able to "invent" and produce the component.

1.1.3 ManuBuild

A current investigation project, which aims to rationalise the European building industry, is called ManuBuild (www.manubuild.org). This Master's project is a part of ManuBuild. ManuBuild's purpose is to supply the European building industry with tools, which aims to ease industrialised building processes. ManuBuild also aims to create conditions for an open European building industry (Kazi et al, 2007). Instead of working with standardised technical solutions, ManuBuild is working with methodologies for, for example, product development. This Master's project addresses this area. But instead of working with development of a building system this project addresses development of structural connections; how should elements within a system be attached.

1.2 Expression connected to connections

Proper interaction between the elements in a house is needed because of many reasons. The most obvious reason is that forces should be transferred between the elements. Another reason is that a house should be tight against, for example, air leakage. The word connection, in a structural context, refers to the interaction between elements where loads are transferred. The interaction could either be discrete or smeared out. In a discrete connection the load is transferred through a clearly limited region (Figure 1.2 a). A smeared out connection convey that the load is transferred over the element length (Figure 1.2 b).

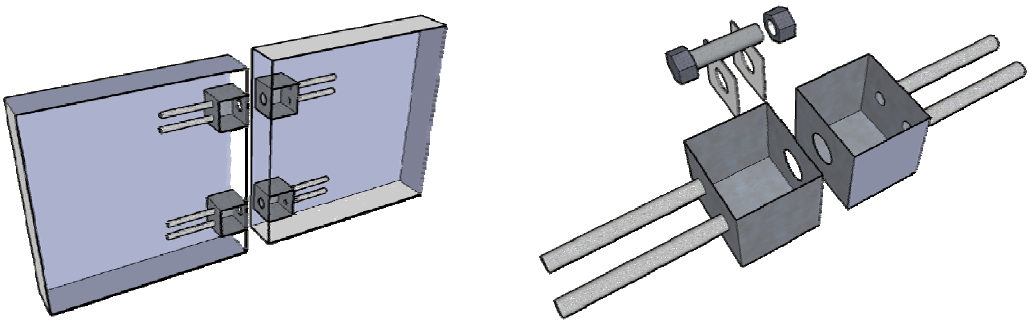


a) b)

Figure 1.2 Examples of different types of connections, a) Discrete and b) smeared out.

It may not always be clearly stated if a connection is discrete or smeared out. For example, tension can be transferred, between two elements, through a few discrete connection points. Compression can in the same situation, be transferred over the whole element lengths, in a smeared out connection. This demands the element developer to design their elements with respect to each load case, i.e. point load or line load. It is therefore important that the intended function of a connection is clearly stated for each load case. When the word connection is used in an air leakage context the connection is always considered as smeared out, since the air leakage cannot be hindered in a discrete connection. Tightness must be provided along the whole joint. This case is, however, of less importance in this Master's project, since it mainly addresses structural connections.

This Master's project differs between the words *connectio*n and *connection device*. Connection refers, as earlier mentioned, to the interaction between elements where loads are transferred (Figure 1.3 a). Further on, the element region that is directly influenced by the forces (disturbed region and anchoring length of reinforcement bars for example) is also considered as a part of the connection. Connection device refers to the physical instrument that is attached to two or more elements, and whose purpose is to connect these elements (Figure 1.3 b). Connection devices can be discrete or smeared out. A connection must not consist of a connection device, e.g. welding or grouting could solve a connection but it is not seen as a device, it rather is a connection method.



a) b)

Figure 1.3 Example of a connection (a) and its belonging connection device (b).

Several connection types are needed in a building system in order to transfer all arisen forces. Another expression is therefore introduced; a *connection concept* refers to a group of connections, which includes all connections that are needed to take care of the arisen loads in a building system.

1.3 Aim and purpose of the Master's project

To get a more rationalised open building system without preventing the possibility for construction of varying architecture and design, industrial thinking should be applied in the development processes.

This Master's project aims to come up with a method for how connections in an industrial building system could be developed. The fact that the project handles how prefabricated elements should be connected means that it involves prefabrication action. This is however not the main focus of the Master's project. Instead, it is the industrial thinking that is the main focus.

To be able to develop a method for connection design the development process is divided into sub activities. The objective of this project is to study these activities in detail. This includes information exchange; during the development process, within and between the activities and between the system development and the connection development. All of these investigations should result in a method, which can help the product development team during the development of connections. With help of the method a development process can be more rational, effective and reviewable and it should also help the product development group to plan the process from the very beginning. An industrial development process should also secure the quality of the product. This agrees well with the industrial thought.

1.4 Method

A literature study about industrial construction and product development was performed. An interview, with a person who has experience from development of a building system, was performed. This was made in order to get an understanding of the procedure. With this knowledge a process for development of connections in an industrial way was produced. This process was described in the form of a guideline. Parallel with this development work a case study was performed to test and refine the process. The case study also gives the reader a picture of how the process will work in practice.

1.5 Scope and limitations

The thesis handles the product development stage only; system development briefly and connection development more comprehensive. The thesis does only handle industrial construction concerning houses.

The connections that are treated in the Master's project are load bearing, i.e. structural connections, but the methods and ideas could as well be used for other connections between non load bearing elements. Consequently requirements and criteria directly connected to structural performance and prefabrication action are emphasised in the Master's thesis. Connections for water, electricity supply and sewage are not considered.

1.6 Outline of the thesis

Below the content of the following chapters are described.

Chapter 2 discusses the industrial building process. Differences between a traditional building process and industrial building process are described. The development process in industrial construction is further described in order to give the reader information about what has preceded the connection development process.

Chapter 3 addresses new product development processes in general. Ideas for how a successful process should be planed. Thoughts about development from traditional manufacturing industry are discussed.

In Chapter 4 different types of requirements and evaluation criteria concerning connections are handled.

In Chapter 5 the thoughts from Chapter 3, about product development, are implemented to development of connection. The developed method is in high extent based on Chapter 5. The four activities, which is the foundation of this Masters thesis is introduced and explained in this chapter.

Chapter 6 consists of guidelines for how a development process of connection should be performed effectively. The connection development method is explained with help of guidelines.

Chapter 7 is a case study in which a connection development process is simulated. The case study should help the reader to understand how the developed method works.

In chapter 8 are conclusions about the Master's project presented.

2 The Industrial Building Process

2.1 Industrial construction vs. traditional construction

In a traditional building process the aim of a new project is to develop and build a new product, e.g. a new house. In contrast to a traditional building process, in industrial construction the product is first developed and a project's aim is to build houses within the already developed product's frames. This can be seen as a development project and the developed product is a building system. When the product is developed projects can be built. A project in this case is one or many houses. This approach is used in traditional manufacturing industry, and therefore the name industrial building or construction. The projects that should be built within the system can be more or less adjusted to the current situation. One system may have only one standard house, and another system may allow changes in, for example, design and architecture. Today the freedom to choose between several options is seen as a very important parameter in industrial construction. This demand concerns the traditional manufacturing industry as well. For example, the person who wanted to buy a T-Ford in the early twentieth century could choose any colour, as long as it was black. If a car manufacturer today had such restricted freedom of choice for the customers the car manufacturer would not sell many cars.

A big difference when developing a building system, in contrast to development of a building project, is the possibility for development of new and creative solutions. The incentive to find new solutions in traditional building processes is, more or less, lost due to the fact that the project's contractor's aim is within the projects boarders. Product development is needed, but hard to motivate since each project's aim is to satisfy the customer's needs to as low cost as possible, in order to gain as big profit as possible. Product development may be too expensive in comparison to the project's budget.

In contrast to a traditional construction project where a predefined amount of buildings are planned, a building system aims to produce bigger quantities. Therefore, development of new solutions suits well and is of big importance in industrial construction, where all details have to be optimised in order to get as big profits as possible.

More over, it is also possible to improve a product in industrial construction. In a traditional building process that possibility is left out; to improve an existing house is only made if inconveniences are detected. It may also cause disturbance and be costly. If an inconvenience is detected in an industrial building product, on the other hand, there are possibilities to do the necessary changes before the next project is build.

2.2 The development process

When a building system should be developed it is important to investigate what the product should aim for. It is therefore important to do a product definition. This concerns all kind of product development; development of building systems and development of connections in an industrial building system as well as other kind of product development. Kahn et al (2005) has included the following parts in a product definition. The explaining notes are adjusted to fit development of a building system.

- Project scope, for example geographical restrictions, domestic or international.
- Specification of the target market, exactly which type of premises that are intended, such as housings, offices etc.
- Description of the product concept and the benefits to be delivered to the user, for example, a flexible system sets the customer in focus, allowing individual demands.
- A list of the products features, attribute, requirements, and specifications are set to emphasise particular parts and restrict the system. For example that a system should contain elements of a certain material and should not exceed a certain number of stories.

How well defined the product, i.e. the system, is may differ from one product to another. A well-defined product makes the development process more convenient and straightforward. On the other hand, a too well defined product may hinder creativity and innovative thinking and good ideas may be left out.

When the product is defined the development phase starts, the definition is evaluated and translated into certain proposals about what the product should contain; what is possible to do within the frames of the definition, resulting in concept solutions. Further on, the longer the development process reaches the more detailed the possible concept solutions will get. For every concept proposal investigations are made and solutions are evaluated. On the basis of the definition and those investigations, the number of suitable concept solutions is reduced as the development process proceeds.

For every concept, investigations about how details are going to be solved, have to be made. For example how the elements are going to be jointed together, which will result in connection development. When this question is of current interest it is time to initiate the connection development process. In which phase of the system development process the connection development starts may differ from one project to another depending on the connections role in the system. Consequently, if the connection has a central roll in the development process it is favourable to introduce the connection in an early stage. If a connection is of great importance and the development of it starts early it has a decisive function, i.e. it can set more demands on other components. It is then decisive for how the development process should proceed.

3 New Product Development

When a building system should be developed it is important to have a convenient development process. One reason is that a well functioning process results in an effective use of resources, which is a central point in industrial thinking. Another reason is the quality of the product; the product should correspond to the customer's expectations. In addition, an appropriate development process allows creative thinking, which is an important aspect of many reasons. This chapter aims to describe aspects of product development in a general perspective, not necessarily in building industry.

The idea can of course also be subdivided and implemented in development of certain components, as for example connections.

3.1 Product development with customers' needs in focus

The company Arkitema (Arkitema.dk) has developed a working method, called "sensemaking" for how customers should be involved in development of building projects, and how innovative thinking could be encouraged (Arkitema, 2006). The method is aimed to be used in a traditional building project. However, the development of a building system can be inspired of those ideas, since the purpose, to emphasise the customers' needs early in the development process is important in system development as well as in project development.

One purpose with the method is to detect the customers' needs, which may not always be clearly pronounced, and also to create conditions for a process that can fulfil those needs. The customers in this sense are the future tenants and users. If the customers should be able to explain their needs, it is preferable that they get inspiration from other buildings and solutions. Further on, the buildings' purpose, i.e. what activity will be pursued by the customers, should be emphasised in order to detect the unspoken needs.

In industrial construction the specific customers and their specific needs are not clearly known during the system development. The buildings can be more specific and adjusted to the specific client's needs in the project development stage. This can be compared to a traditional building process where the customer is more or less known. This means that a target market has to be decided, i.e. the range of customers must be set first, and after that the needs can be defined. The fact that the tenants are unknown demands the system to be flexible within the range of the intended customers' needs.

In development of connections and other components the customers of the system, i.e. the future tenants, are no longer the primary customers. Instead the primary customers are represented by the system itself and its developers. And the future tenants' demands are here only affecting the component development indirectly. One can say that, as long as the demands on the system are fulfilled the tenants' demands are fulfilled. In which way the components fulfil their requirements are not of interest for the tenants as long as the houses correspond to the product they wanted.

3.2 Articulated activities ease the development process

To get a well structured product development process without preventing innovative and creative ideas and solutions, it is important to have a general overview of how such development will precede. Rainey (2005) claims that the key to a successful product development is that activities within the product development is predefined and well articulated and that all participants and resources are well coordinated. The activity thinking is also stressed in Arkitemas method, "sensemaking" (Arkitema, 2006). The purpose is to describe each activity in order to clearly state what the task is in each stage. Since it is beneficial for planning of the development process to have an overview of what to do, it is necessary to know which activities that should be included in the process. Which activities that should be performed, and their purpose, can be stated from the beginning, whereas the actual content and procedure will be clarified during the process. One way to illustrate the different activities is with rhombus, where the first rhomb corresponds to the first activity etc. (Figure 3.1).

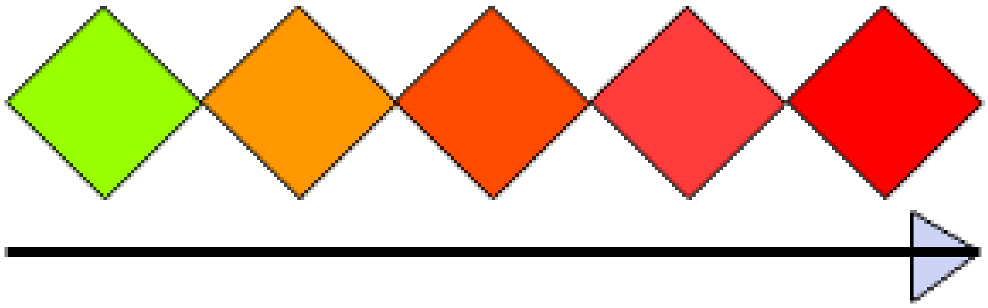


Figure 3.1 The activities in a development process illustrated as rhombuses.

The aim with an activity has to be clearly stated when it starts. An activity's aim can either be "physical", as calculating component dimensions or be "unphysical" as prescribing a definition or stating requirements. How the aim of an activity is fulfilled is not regulated, and the involved architects, engineers and other participants are allowed to use their creativity in order to produce innovative solutions. In addition to the aim, an activity starts with certain input data given from the previous activity, e.g. requirements or conceptual solutions. Moreover, in the beginning of an activity a working plan should be clearly stated. The plan should contain which task each participant has and also a time plan.

An advantage with clearly pronounced and predefined activities is that all involved actors of the product development know what result to deliver and when it should be delivered. Within an activity the involved architects, engineers and other participants have the possibility to think freely and are not restricted to anything else than the input data and what the activity aims to deliver. If the activity is not well pronounced a person may think that he/she has a lot of time to develop a couple of conceptual solutions. He/she might then do a rigorous investigation. When the project leader decides that that particular part of the development process should be finished the developer have only made ruff suggestions, which do not compile with the project leader's expectations.

Clearly pronounced activities make the work easier for the project leader, since he/she has a clear view over the projects progress and a clear assignment to conclude an activity and decide to begin the next one. In that case, "the point of no return" is reached. Such breakpoint corresponds to where the involved parts confirm that their performed work fulfils the aim and that the project leader confirms that the next activity can begin. The risk with a process without any predefined activities is that resources are incorrectly distributed and that a too distant deadline reduces the motivation. It is easier to work effective when the goal is reachable. More over, when the task is clarified all irrelevant work can be rationalized and the focus can be on the real task. Further on, it is necessary to have well defined activities in order to coordinate different actors. Otherwise, one actor may put in a lot of effort to complete his/hers task, but has to wait for data from another actor that have not completed his/hers task; the actors' work is out of phase.

If no activities are predefined no breakpoints, with compatibility control with the rest of the system development, are planned. Hence, there is a risk that mistakes and miss aimed choices may be detected too late. In worst case, an early made choice that is not compiled with the rest of the development, will affect the following work in such great extent that big efforts must be used in order to recover the mistake. The consequence will be a product that does not comply with the aimed one.

3.3 A broad view gives better solutions

The fact that the approach in Section 3.2 suggested a development process that is irreversible, in the sense that when an activity is ended there is no turning back, forces the actors to produce the "right" solution from the beginning. This demands a high quality level on all solutions that are delivered at the end of an activity. Hence, it is very important that the first activities are "broadening the view" of the project; interpret the aim with the project, do researches about the subject and needs from the intended users and gain knowledge about how different decisions will affect the consecutive work. Ottosson (1999) means that to be able to find solutions for user- and usage demands, one has to abstract the task before more concrete solutions are chosen. This to allow that a lot of possible solutions are treated instead of choosing the solution that is most common. It may turn out that the common solution is the best after the evaluation, but at least it has been more critically reviewed in that case.

The approach to first broadening the view and then align to a more detailed solution is applicable on activity level as well as on project development level. This means that when an activity begins the situation is very clear; one knows what to deliver and within which frames, on the basis of the previous activity's results. One can think that the progress in this situation should be to, as fast as possible, find a proper solution that suits the activity aim. This may, however, exclude many other solutions that will fit the aim as well. It is important to have a methodical progress; the first idea may not be the best even though it has worked before in a similar situation. Instead, the developers should be patient and come up with several possible solutions and investigate their consequences.

3.4 How and when to make decisions

It is important to beware of how different decisions procedures will affect the development process, i.e. many small decisions or a few big decisions. Ottoson (1999) argues for that many small decisions promote an effective process due to the fact that the importance level of a single decision is decreased. This allows decision making on a lower level in the organisation, i.e. each participant of the process has more influence in the decision making, and the need for a detailed long time planning is not demanded. This also spreads the risks and if one decision is wrongly made the process for correcting it becomes easier; one can say that the process is dynamic. The opposite of the above mentioned decision model is the centralised decision model where all decisions are made higher up in the organisation; this leads to fewer and bigger decisions which increase the risks for big redoes if it turns out that a decision is not optimal or wrongly made. This also demands a detailed long time planning and the flexibility of the development process may be hindered. In addition to that, it is harder to affect the development for participants lower in the organisation. The process becomes more static than when process allows small decisions, as described above. In order to ease the communication within an activity, as well as avoiding the above mentioned risks with to infrequent and big decisions, each activity should have continuous and close in time breakpoints.

3.5 Quality assurance

The communication process can be seen as a quality system, where each step in the development has to be approved. For each phase in the development stage each developer has to assure the quality of his/her component, i.e. make sure that the given requirements and evaluation criteria are fulfilled, which can be seen as a self check. In some stages the component's quality has to be assured by someone with an overview of the whole system, i.e. the product development group. This quality check should assure that the component is compatible with the rest of the system. Since the development of the system is an iterative process the conditions may change during the process. These changes may as well change the demands on the components. It is therefore important that someone with an overview of the entire system can communicate new demands to the component developers and make sure that the demands are fulfilled after each stage. If the developers work on a connection on the basis of demands that are not up to date much work are done without actual progress. This can be compared with "over the wall design" (Boothroyd et al, 2002) where the designer creates drawings without feedback from the manufacturing engineer, which leads to the fact that the manufacturer must deal with all arising manufacturing problems because he/she was not involved in the design phase.

In order to re-call the ideas from Section 3.2 (the development process should be divided into activities), and to couple it with the quality assurance, each break, between two activities, should function as a quality control. This is illustrated in Figure 3.2. Each activity is iterative with clearly stated breakpoints between the activities.

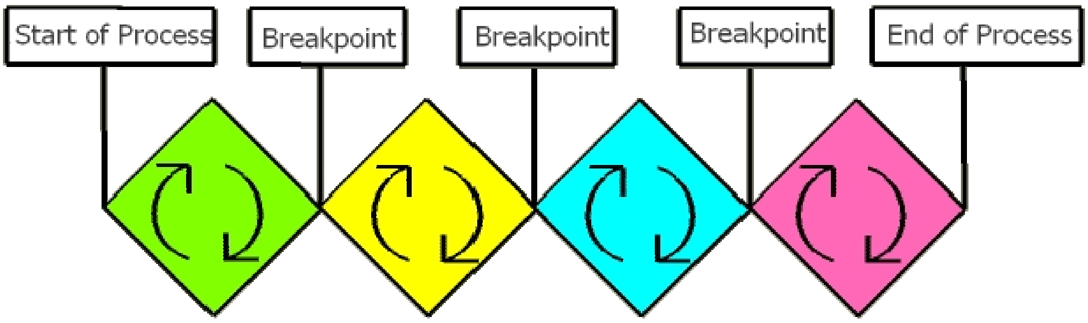


Figure 3.2 The activities in the development process are iterative. Clearly defined breakpoints are stated between the activities.

In addition to assurance of the quality the breakpoints should function as project break points. It is well suited to put the question: can this development process be result in a product that provides economical profits. Without clearly stated breakpoints it is difficult to end a development project, even though it seems to have small opportunities to succeed.

4 How to Judge Connections- Requirements and Criteria

Two approaches to judge a connection are stated in this Master's project. The first approach is to judge on the basis of absolute requirements. These requirements can be judged with a "yes" or a "no". All absolute requirements must be fulfilled for a connection that is acceptable. The absolute requirements are divided into two groups, authority requirements and system-regulated requirements. The other approach to judge a connection is on the basis of evaluation criteria. These criteria cannot be judged with a "yes" or a "no". These criteria can be fulfilled to a high extent or a low extent. An evaluation criterion may be very important for the system or it may be less important.

Absolute requirements and evaluation criteria can either be quantitative or qualitative. Quantitative means that an actual number can be set on the requirement or the criterion, e.g. the connection should be assembled in ten minutes. Qualitative means that the judgment is made on the basis of non-measurable parameters, e.g. an architect judges a connection on the basis of how well it fits into the system from an aesthetically point of view.

More over, an evaluation criterion can be converted to an absolute requirement if an absolute limit is set. For example, an evaluation criterion is that the connection should be fast to assemble. When more information about the system becomes known it is decided that the connection, which should be chosen, should be assembled in ten minutes.

This chapter aims to describe different types of absolute requirements and evaluation criteria concerning connections. Notice that the number of requirements and criteria that can be set on a connection is more or less immeasurable, and hence the authors do not have any intention to find or list all of these.

4.1 Absolute requirements

The primary safety requirement on a building is that it should not collapse during its service life, which off course can be applied to the connections as well. Therefore, a connection design has to fulfil certain requirements from norms, regulations and standards.

Other requirements that are decided on the basis of regulations and that concerns the connections are for example sound and indoor climate. These requirements have a certain limiting value that must be reached and that are valid for buildings constructed in factory as well as buildings constructed with traditional methods. These requirements are regulated for the whole building and should be sub-divided to requirements on the components.

4.1.1 The connection's role in the structural system

From the absolute requirement that the building should withstand all conceivable actions during its service life, an idea follows of how the structure is going to take care of these actions. The idea of the structural behaviour gives the requirements on component level, e.g. connections. The opposite is also possible, that the components set requirements of how the structural system should be designed.

The connections are intended to withstand different types of action, shear forces, normal forces and bending moments for example. These actions are directly linked to the building's structural system.

4.1.2 Load bearing capacity

There are two main load directions that a building has to withstand, horizontal and vertical. The first mentioned arises mainly from wind loads, inclined elements (intended or unintended), imposed loads and accidental forces and should be resisted by stabilising functions transferring the loads to the ground. The latter one arises from self-weight, snow loads, imposed loads and accidental loads and should be transferred through the structure down to the foundation. All of these loads have to be resisted by the house. In addition to these actions, the design must consider that the building is affected by different types of loads in different stages of the building process. An example is when a wall element is designed to be stabilised by an adjoining element, but before the adjoining element is assembled the wall element has to be self stabilising, which causes new requirements on the connection, i.e. it should also be able to withstand moment forces.

Moreover, it is important that buildings perform during their whole service life. Therefore, buildings as well as connections have to be designed to be accessible, in order to do inspections and maintenance work.

4.2 Evaluation criteria

In order to be able to choose a suitable connection that fits the system well, evaluation criteria are set. Every criterion must not be perfectly fulfilled for the chosen connection. Instead the emphasised criteria should be fulfilled to a high extent and the criteria of less importance must not be fulfilled in such high degree. Therefore every evaluation criterion must be weighted with regard to its importance to the system. The importance should be chosen on the basis of what is emphasised in the system definition. Moreover, it is preferable to have a minimum value of what a criterion should fulfil. Evaluation criteria can occur from different sources.

The first source is the system; what must the connection fulfil in order to fulfil the absolute requirements and evaluation criteria on the system? An example is: how thermally tight must the connection be, in order to fulfil the requirement on a minimum indoor temperature? The indoor temperature is an absolute requirement, regulated in codes, and all building parts and components must cooperate in order to fulfil the systems absolute requirement. Hence, it is off course preferable that all building parts perform as good as possible. The system's absolute requirements are translated to evaluation criterion concerning the different building components, e.g. the connections.

An example of when an evaluation criterion concerning the system is transferred to an evaluation criterion concerning the connections is when a connection should be judged from an aesthetical point of view. The system should be judged on the basis of an aesthetical criterion and, hence this criterion has to be translated to connection level.

Further on, the second source of the evaluation criteria is other criteria on connection level. An evaluation criterion or an absolute requirement is translated to several sub-criteria when they are more specified. An example is that the connection should be sustainable, which can be translated to the criteria for inspection possibilities and maintenance work possibilities.

Evaluation criteria occur during the whole development process, it is more or less impossible to list all necessary requirements from the beginning. New evaluation criteria must therefore be clearly communicated to all concerned people.

4.3 Requirements connected to prefabrication

The basic idea of prefabrication action is to have no, or little, supplementary work on site. This result in a high level of completeness of the elements when delivered to the building site, therefore traditional jointing methods such as, welding and grouting should be avoided. The main reason is that these are time-consuming activities, which does not agree with the basic principles of industrial construction. Another reason is that they may pollute the more or less completed elements at the building site. Wallpapers, kitchens and other sensitive parts must be covered or cleaned when a polluting jointing method is used. This leads to more supplementary work.

A connection that agrees with the basic principles of industrial construction should be easy to assemble; a method for doing such a design process is called DFA, Design For Assembly. Additionally, there are similar methods for, for example, manufacturing, DFM (Design For Manufacturing), which can be used depending of what the product is aimed for. (Jürisoo and Staaf, 2007)

Assembly of elements demands smaller tolerances than traditional in-situ construction, since the elements are already fabricated and must fit together at assembly. In traditional on-site construction deviations can be corrected during the building process. In contrast to that, in industrial construction a deviation may cause, either that elements cannot be assembled or that the deviations are propagating, i.e. a small deviation on component level may propagate and cause major displacements on structural level. This issue can be solved with two approaches, a flawless planning and manufacturing or with connections that can handle the deviations. A perfect system does not allow any manufacturing mistakes and may be difficult, or even impossible, to achieve. Therefore, it is preferable that the connections tolerate deviations.

However, the tolerances are tighter and more important to fulfil than in traditional on-site construction.

Except from that the connections should function in the structural system; they must as well withstand all conceivable loads during the assembly process, i.e. connections must be designed with regard to the intended assembly method. An example is, before a stabilising wall is assembled, adjoining elements must be able to be self stabilising if no temporary bracings are intended.

Another issue that has to be considered is the manufacturing method. A method for designing for manufacturing is, as earlier mentioned, called DFM. To consider manufacturing early in the process is important since it is necessary to develop a connection that is possible to manufacture. It is also easier to optimise the connection regarding manufacturing when the issue is considered early in the process.

4.4 Connection requirements on the system

This chapter has mainly described how the system sets demands on the connections. It is however important to explain that the opposite is possible as well. For example, if a wall element should be lifted in the connections, it must be designed with regard to that load case. These requirements can be decisive for which connection that should be chosen. A requirement that affect the system too much may exclude that particular connection. It is therefore always necessary that the requirements are clearly stated and communicated to all persons concerned.

5 Connection Development – the Containing Activities

As mentioned in Chapter 3 a successful product development process demands well-articulated activities. This chapter aims to describe four well-articulated activities, which suit well for connection development. The activities that are chosen are: *Definition,* where the structure of the development should be stated. *Conceptual design* means that a couple of solution should be invented. *Evaluation and improvements* aims to select the best conceptual design. *Detailed design* aims to do the final design. The activities are illustrated in Figure 5.1 and are described more comprehensively in this chapter. One important aspect during the development process is the information flow between the system development group and the connection development group. This information flow is visualised with arrows in Figure 5.1. It should be emphasised that these activities may not be suitable in all situations and that the activities should always be optimised with regard to the current situation.

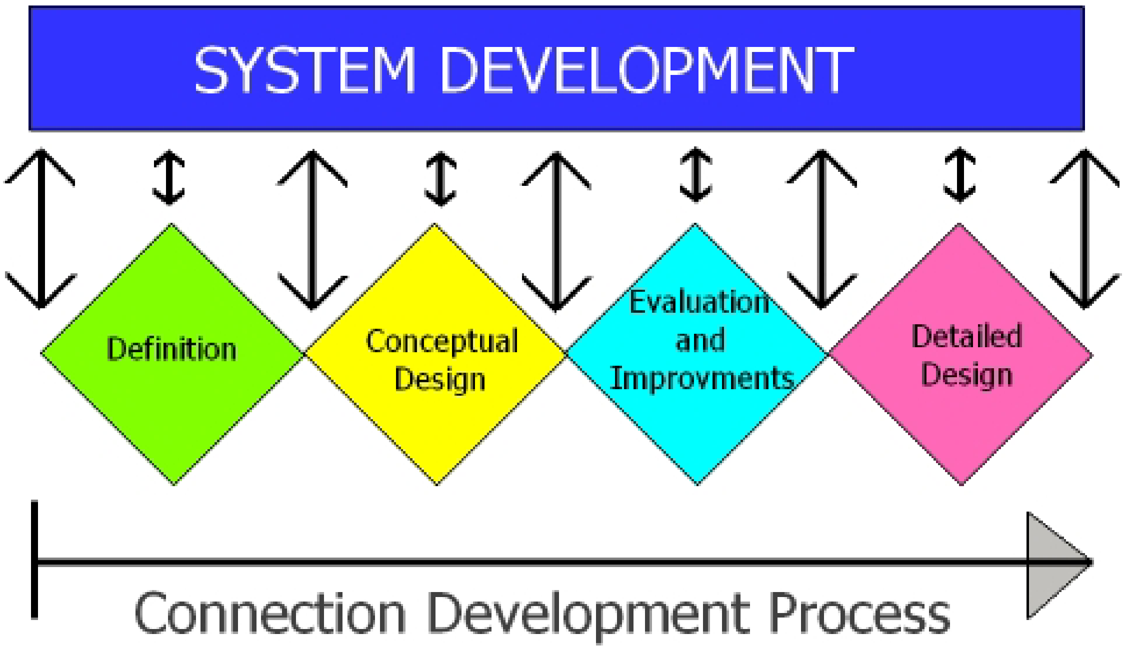
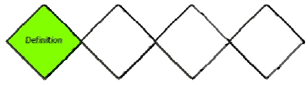


Figure 5.1 The connection development process with the including activities illustrated as rhombuses. The arrows illustrate the information flow between the connection development and the system development

5.1 Definition



Two sub-activities in the definition activity can be found. The first one concerns a definition about how the development work should be treated, which activities that should be included in the process, how responsibility is divided, how the information is going to be shared and other effects that concerns the development process. The second sub-activity concerns the connection itself. It can be seen as a translation from the system definition into basic conditions that are decisive for the connection development, e.g. level of flexibility. These sub-activities are dependent on each other, they should, hence, be carried out parallel.

5.1.1 Structure of the connection development process

Forming a group

Firstly in a development process a project group has to be organised. There are several important group psychological issues to be aware of when a group should be composed (Monplaisir and Singh, 2002). Monplaisir and Singh claim that a well composed group can perform much better than one individual can do, since many professions, knowledge and approaches can be gathered. However, there exist traps that one has to be aware of when putting a group together. Monplaisir and Singh emphasise four major reasons why groups do not perform as well as expected: *Participation*, everyone at a meeting can not talk at once, which leads to unnecessary waiting time. *Conflicts* can reduce the communication between participants and winning the conflict becomes more important than making the right decision. *Group think* is when members are pressured, for different reasons, to get along with the other members, and the decisions can become incorrect because no one argues with the made decision. *Group polarization* is a phenomenon that means that members' opinions tend to be more extreme than they originally where. These reasons, of why groups may not always perform as good as expected, should however not lead to the conclusion that groups should not be used in development processes. These reasons should instead lead to the conclusion that groups should be used with consideration about problems that can occur. Ottosson (1999) claims that a project development group should be located at the same geographical place, in order to reach as good results as possible. This will encourage informal meetings and shortening the communication paths. This may, however, not always be possible since development processes concerning a building system contains people from several companies and they may have other parallel work assignments. It should be stressed that technology has developed since the book was published. It is easier today, with help of modern technique, to work on different geographical places.

The connection development group must contain several professions and qualifications in order to utilize the benefit with a development process group. The professions should, for example, contain knowledge about acoustics, structural engineering and indoor climate, and in addition people that have knowledge about and responsibility of the elements in the system. The leader of the connection development group should have influence of the system development, since there must be a continuous communication process between the system development and the connection development.

Planning the process

The second thing to decide is which activities that should be included in the process. Different circumstances demands different project organisation and the project plan should off course be optimised to fit the current situation. Before the definition activity is concluded the approach of the following activities can be changed. The aim with each activity should be decided during this first activity. The actual content of an activity may however be decided in the beginning of the activity. When the activities are confirmed by all participants a time schedule should be set; when each activity should begin and be finished. Since the development process may go on over a long time a detailed time plan cannot be set in this stage. A more detailed time plan for an activity can be set in the initiation phase for the activity. The time plan must be coordinated with the time plan that is set up for the system development. This means that the connection development time plan is very restricted and must be adjusted to the general system development. To know when a connection development activity can start and end it must be analysed when certain system related decisions and activities are made and concluded. It is, of course, preferable to do this analysis already in this early stag. It may however not be possible. As the system and connection development processes proceed the more the time table can be accurate.

Responsibility distribution

Responsibility distribution is another important area that must be clarified in the definition activity. It may, however be difficult, or impossible, to decide the responsibility distribution within the latter activities. It may not even be known who the people that participate in the latter activities are, since different professions are wanted during different activities. To have the same people during the whole development process is preferable, even though it may not be possible in all situations. When different groups take care of different activities, called over-the-wall product development model, there is a risk that much work has to be redone, and unnecessarily efforts are spent (Trott, 2002). Hence, it is suggested that, at least, a core of the development group should work continuously through the whole process. This will lead to that the group has an understanding of earlier made decisions and superfluous time to questioning previous work disappears.

Information exchange

Another important decision is how the information flow should be treated. The most obvious reason, for a well functioning communication process, is to make sure that the participants work with conditions that are up-to-date. Another reason, maybe not that obvious, is that the development group should have a possibility to follow up previous made decisions, and their influence of the development process. Lessons of mistakes made can be learned and the next development process can be better and more effective. Ottosson (1999) suggests that every participant in the development process should make diary notes for every progression in the development. These diary notes can be important in the future, if for example juridical disputes concerning patent-rights and other issues occur. Ottosson (1999) also suggests that the participants should write a weekly report, which should be handed out to all other participants, where the progression and the discrepancies should be announced and also a suggestion about what the work for the next week should contain. The weekly reports could for example be handed out via internet, mailing-lists or web pages with access for the development project's participants.

On the basis of these weekly reports the project leader should make a development project report. When the development project is finished conclusions about the development process can be made. This feedback of knowledge and experience suits well with the idea of industrial thinking. The authors do not prescribe that the reports should be weekly, but does however emphasise the importance of continuous report. The report of the connection development can, however, not function alone, a system of how system development process is reported should already have been stated and the connection development report can be an emphasised part of that report.

One essential thing that should be communicated is the requirements and evaluation criteria on the connections. To list all requirements at this early stage may be very difficult or even impossible. Ottosson (1999) means that a list, with predefined requirements, makes the product development group relaxed and less alert. Instead a list should be prepared during the first activity; it should then be filled in during the development process, when more information about the system and the connection becomes known. A convenient method is to explain all new requirements in the reports that are carried out continuously and at the same time add them to the requirement lists. The requirements can then be installed into a table where it is shown which sub-development that is influenced by which requirements (Ottosson, 1999). An example of such table is shown in Table 5.1. This table should be stated by the system development group, since it concerns all sub-developments.

Table 5.1 Table that shows which sub-development that is influenced by which requirement.

	Sub-development			
	1	2	3	4
Req 1	X		X	
Req 2	X		X	
Req 3	X		X	
Req 4		X	X	
Req 5		X		X
Req 6		X		X
Req 7				X
Req 8			X	X

Information exchange does not only exist in written format. Important decisions are often made during meetings. It is important to have a strategy and a plan of how, and when, meetings should be organised. In some cases it may be preferable to have weekly meetings and in some other cases it is better to have meetings in crucial stages. It is very important to have meetings when an activity starts and when it ends. The concluding meeting for one activity can be organised in combination with the start meeting for the next activity.

An important aspect about information exchange is how the information should be shared between the connection development group and the system development group. It is essential that both groups are working on the basis of the same information. Similar development processes, e.g. about wall- and floor elements, are going on at the same time. Hence, it is preferable that some of the people participate in both the connection development group and the system development group. This will reduce the risk of an "over-the-wall process" (See Section 5.1.1 *Responsibility distribution*).

5.1.2 The connection

During the same time as the definition concerning the connection development process is set the connection development group should set a definition concerning the connections. The connection definition can be seen as the aim with the connection development. As described in Chapter 2, a definition for the system is set in the beginning of a development process. The definition can be interpreted and basic conditions that are decisive for the connection development can be identified. Examples of basic conditions that are decisive for the connection development and directly implemented from the system's definition are:

- *Type of system: planar, skeleton or volume elements.*
- *Level of flexibility: how flexible should the system be, widths, heights etc.*
- *Multi functionality: should an element type be universal or should the system contain several different element options that all are optimised to fit its specific task.*
- *Importance of fast assembly: assembly is decisive for the system design, and connection details are therefore emphasised.*
- *Importance of a certain element type: the system design depends in big extent on a certain type of element.*
- *Architectural aspect: may restrict the system and exclude solutions on connections and elements.*
- *Economical aspect: how crucial is the connections for the system, and how large resources can be put on development of the connections.*

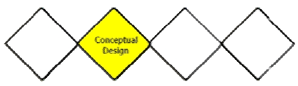
These basic conditions concern the building system. They can however be translated to requirements and criteria concerning the connections. Chapter 4 described that two approaches for judging connections are possible, evaluation criteria and absolute demands. The basic conditions mainly results in evaluation criteria. It is therefore important to investigate how important the different criteria are.

The greatest difference between system definition and connection definition is the importance of having the customer in focus in the system definition. The system's regular tenants do not care of the connection design, since it mainly is a technical detail. This means that one aspect that is of great importance in many product development methods disappears, which thus means that the focus in connection design should be on fulfilling the system definition.

During this activity, it is important to do investigations about the consequences the connection definition will give for the system, for the connections and for the development process. The proposed approach is to presume basic conditions and then simulate the consequences in order to find out as much as possible about the made choices. The procedure is repeated until the connection development group have found a definition that is achievable and that fits the system definition. This can be seen as a trial and error procedure.

Another important aspect, which should be considered in the definition activity, is to do a risk analysis. This is done in order to predict eventual mistakes in the design and predict risks from the world around, such that a deliverer can go bankrupt. When the risks are detected, a plan, of how to handle the eventual risks, has to be stated.

5.2 Conceptual design



After the definition is set the actual development work can begin. The aim with this activity is to come up with a few (but not a predefined number) conceptual solutions of how the connections can be designed. This is a very crucial stage in the development process, as described in Chapter 3 it is important not to run into, and work on, the first solution that comes up. Ottosson (1999) emphasises the importance of not trying to find detailed solutions early in the development process, since it blocks the creativity. In contrast, the first part of this activity should contain a discovering phase; discovering about existing solutions and about what consequences the solutions will bring to the development process. In addition to discovering the first stage of the activity should contain a brainstorming phase. It is then not necessary to look directly on the definition; the important aspect in this stage is the innovation and the creativity; to come up with many ideas. One can say that the quantity is more important than the quality, since the irrelevant solutions will get rejected later in the process. Ottosson (1999) suggests that during a brainstorming meeting, when the creativity is inhibited and no innovative ideas come up, the project leader should give a “crazy” idea since it can ease the dialog and trigger the creativity.

When the group has come up with several conceptual solutions the next phase is to eliminate the misaimed ones. If the product development group has worked creative and has come up with many solutions there are most likely many that can be rejected with no further discussions. The further evaluation is going to be carried out with help of the evaluation criteria that were set in the first activity. It is important to emphasise that it is not only one solution that should be chosen in this stage, instead at least a couple of promising solutions should be elaborated. To develop several connections parallel means that important decisions about the connection design can be made later in the process, when more information about the system is known, which means that the risk of impropriate connections is decreased, which can be seen as a quality enhancer.

To do conceptual design on a couple of connections, when only one is going to be chosen, can seem as a waste of time and resources. Above, it is explained that the quality aspects is one reason why many connections should be handled. Another reason is that the concepts can be used for future system development processes. A company can gather the concepts in a connection bank and the concepts can then be reused in the next connection development process.

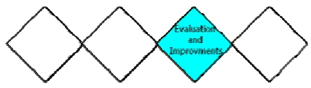
The cost for developing concepts is easy to predict, since the cost is mainly connected to the participants' salaries. Ottosson (1999) claims that the costs for the stages before the prototypes are constructed should, and can easily, be kept at a low level.

Meanwhile the connection is developed the system and its containing elements are developed. This and the fact that the connection design is directly dependent on the system design lead to several important conclusions. The first is that the communication between the two development groups is very important. The connection development group has to do conceptual solutions on the basis of the correct input. If for example the connection development starts early in the system development process, when little information about the system is known, the connection development group may have to wait for information from the system development. Hence, the conceptual design is not continuous; several, shorter and longer intermissions can occur. This emphasises the earlier mentioned conclusion that the progress of the first phase within the activity, discovering and brainstorming, should be slow. The less information that is known, the slower the progress should be and the broader the view must be. The information from the system development is often transferred continuous during the connection development process. Another approach is also possible, that all major decisions concerning the system design are made already before the connection development starts, in that case the connection development group has much input data to work out of and the progress can be more concentrated and rapid. One of the most important decisions that have to be made, in order to be able to develop the connections, is choice of structural system; how the loads, horizontal and vertical, should be taken care of. If, for example, the structural system is not chosen before the conceptual design starts more solutions have to be invented, since different structural systems demands totally different types of connections. In that case, the solutions can be divided in different groups, e.g. one group that demands the system to consist of concrete walls, and another of framework of steel. Every solution sets requirements on the system, on the basis of those, and other requirements from other sub-development processes, the structural system can be chosen. This is, however, a decision made on system level. Consequently, the requirements on the system from the connection development must continuously be reported to the system development group. When the system development group has made a decision, about which structural system that is chosen, the progress, of the connection development, can be much more concentrated and also faster.

As explained above, the connection development can gain more knowledge dependent on how far the progress of the system development has reached. Thus, the activity must be iterative; when new information becomes known the concepts may have to be redone.

Another issue that has to be considered in this activity is the difficulty to know when the conceptual solution activity can be concluded. It is of great importance that the system has reached a certain degree of development. Otherwise, great problems can occur. For example, if the connection development has resulted in three connections that all requires a framework of steel, but the system development group has not decided that a framework of steel is the best structural solution. In that case, the connection development has had a too fast progress. A convenient rule is that the conceptual design activity never should be concluded before the structural system is defined. It should be emphasised that in some cases the structural system may have been defined already before the connection development starts. There might be other important decisions on system level that have to be made before the conceptual design of connections can be concluded, and these must of course be communicated to the connection development group, in as early stage as possible. A check list with decisions that has to be made in order to conclude the conceptual design should be set up.

5.3 Evaluation and improvements



The aim with this activity is to go from a few connection concepts, which where the result of the conceptual design, to only one concept, which is the one that should be used in the system. To achieve the aim with the activity all concepts should be evaluated with regard to the criteria, and the definition, that have been stated in the earlier activities. Different evaluation methods could be used in order to choose the best solution. The final decision can be made when a real sophisticated evaluation system that considers all aspects of the connection design, and the connection design's affects on the system, has been used.

5.3.1 Evaluation methods

Different evaluation methods should be used in different stages. In the beginning of the activity the evaluation can consist of judgements by experienced people. The judgments should be on the basis of the criteria that are set up. These judgements may reject some connection solutions. They may also exclude evaluation criteria if all connection concepts are similarly judged regarding a certain criteria.

As the activity proceeds the methods should be more sophisticated. A sophisticated evaluation method should be able to weight the different criteria with regard to their importance to the system. Weighting can be done in different ways. The most convenient way is to set grades on the criteria; an important criterion gets a high grade and an unimportant criterion gets a low point. The weighting could also be more accurate as the activity proceeds, when more information about the system becomes known. However, the connection definition should always be the foundation of the evaluation. Jürisoo and Staaf (2007) have developed a method for evaluating connections with regard to easy assembly. The method consists of sixteen criteria that each should be weighted from zero to two. Each criterion consists of three statements, which is given the points -1, 1 or 3, and the statement that best represent the connection should be chosen. This method could be redone, so that it covers other areas that have to be considered as well. An example of a criterion is shown in Figure 5.2

Stability	IMPORTANCE: 0	
Connections that provide stability fast and easy are preferred as the time needed for crane operations will be reduced.		
STATEMENTS	**CHOICE**	**GRADE**
The connection provide stability at once		-
Stable after a small fixation or adjustment of the connection		
Major fixation operations or temporary supports are needed		
Comments and assumptions:	*The element is stable with no help from the studied connection.*	

Figure 5.2 Example of a criterion for evaluating connections with regard to easy assembly, Jürisoo and Staaf (2007).

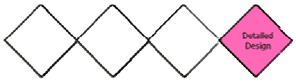
5.3.2 Testing

Another method to evaluate the connections is to perform tests. Testing can be made in different ways. The most obvious way is full-scale trials. This is however an expensive method that is best used in the latter part of the activity. Before real-life tests are carried out simulations ought to be done. A convenient way to test the solutions is with help of VR (Virtual Reality) simulations, which can simulate assembly order and identify problems that can occur. These tests should of course be a help to evaluate and reject connections.

5.3.3 Improving the connections

During this activity the design of the solutions should be improved. The evaluation can show that a connection solution has a certain problem area and if that problem area can easily be fixed there is of course no reason to wait with the improvement actions. In contrast, improvement actions are very important actions in this activity.

5.4 Detailed design



This activity aims to do a design that can be directly implemented in the system's future projects. The design should fulfil all requirements and criteria in the lists. It is important that the connections are designed with regard to the correct load amplitudes. Hence, parameters from the system must be known, e.g. height, widths and wind loads. It is important that this issue is considered earlier in the process and assured that the chosen solution can handle all forces; in other case the development has to be redone. Further on, it should be decided where and in which situation each connection fits, e.g. in a house with four storeys: chose version one, and in a house with eight storeys: chose version two.

It is also important to make the connections ready for manufacturing. The connection device itself should first of all be manufactured. In addition to that the connection devices should be implemented in the element manufacturing procedure.

6 Guidelines – Method for Connection Development in Industrial Construction

On the basis of Chapter 5 where a new product development process with containing activities where discussed, this chapter aims to present guidelines that can serve as a help for a development group during the development of connections in an industrial building system.

6.1 General advice for connection development

General advice that should ease the connection development is presented in this chapter. This is given as general advice since it does not belong to a certain activity; the advice is rather valid through the whole connection development process.

- The leader of the connection development group should have a good knowledge about the system development; he/she should preferably be part of the system development group. It is also preferable that the other members of the connection development group have an insight in the system development. This is important since it will ease the communication and create an understanding of the decisions made in the system development group.

- The members of a group and the group structure are important parameters for how successful a project will be. Therefore, it is preferable that the leader of the connection development group has knowledge and experience of how groups should be organised and what type of personalities that are needed to form a successful team.

- It is preferable if the project development team contains the same members through the whole development process. This will rationalise the process; the members has an understanding of the preceding development process and earlier made decision does not become questioned unnecessarily.

- Keep a journal; it is much easier to follow up and understand the process afterwards if every decision is noted. Another aspect is if discrepancies, with for example juridical context, appear. In that case it is favourable to be able to show how the progress of the process has been carried out. With help of the journal a follow up could be carried out, which will point out mistakes and other things that could be learned. The journals should be compiled in a project report, which could ease future connection development processes and make it more efficient.

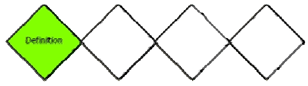
- Save conceptual solutions for future development processes. They might suit well in a future building system.

- Predefine which activities that should be included in the development process. The following chapters give a suggestion of four activities that could be used in the development sections. Each activity should start and end with a meeting.

The start meeting should give the involved members the conditions for how the aim of the activity should be reached and the end meeting should confirm that the activity could be included.

- Each activity should be iterative. The development process is, however, not iterative. Each start and beginning of an activity is a clear breakpoint. When an activity has started the possibility to go back to the former activity is lost. A breakpoint is also a good opportunity to decide whether the development process should continue or not.

6.2 Definition of the connection development



The first activity is called definition and the aim is to state how the connection development process should be carried out and to make a definition of what the developed connection should fulfil. The definition activity is divided into two sub-activities; the first sub-activity concerns the structure of the development process and the second concerns the connections themselves and should result in a connection definition, which is a translation of the system definition.

6.2.1 Structure of the development process

- The group leader's first task is to organise a group with needed professions and personalities that fits each activity. A responsibility distribution within the group should also be set, i.e. the members' tasks.

- State all containing activities in the connection development process and confirm them with the system development group. Decide what should be delivered in the end of all activities, i.e. the aim with each activity. A time plan, should be stated, which needs to be coordinated with the system's time plan.

- State how information should be delivered: how the participants should be informed about necessary news, mailing lists, meetings etc.

- Initiate a risk analysis in order to detect possible inadequacies with the design, and how these could affect the building system. Both inadequacies within the system and outside. An example of risk analysis within the system is what the consequences will be if one connection fails during its service life. An example that concerns the system development indirectly is the effects of rising material prices or a contingent bankruptcy of a connection manufacturer. The risk analysis should be further filled in during the development process.

- State which documents that should follow the development process. Suggestions of documents are presented below:

- *Absolute requirement table:* All requirements that can be judged with yes or no are included in this table. All requirements should be fulfilled for an acceptable design. An example of such table is shown in Table 6.1.

Table 6.1 Example of what an absolute requirement table could look like.

Nr	**Absolute requirements** The connection should…	Fulfilled Yes/No
A1	Be able to resist all applied forces	
A2		

- *Evaluation criteria table:* The aim with each criterion should be set. An example of such table is shown in Table 6.2.

Table 6.2 Example of what an evaluation criteria table could look like

Nr	**Evaluation criteria** Parameters:	Aim: The connection should…	Comments
E1	Visibility	Not be clearly visible	Supplementary work may be necessary
E2			

- *Activity completion table:* State which tasks and decisions that should be made in order to conclude an activity. The table should include which actor that can approve if the task or decision is fulfilled. The aim with each activity can be included in the table already at this stage. An example of such table is shown in Table 6.3.

Table 6.3 Example of activity completion table, an activity can be concluded when all sub tasks or decisions are made, i.e. when the boxes of interest are ok.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	
2	Come up with a couple of connection concepts		X	
3	Select one concept.		X	
4	Optimise the connection and make it ready for manufacturing		X	

- *System requirement table:* A connection can set requirements on the system. These requirements should be inserted in the system requirement table (Table 6.4). The system development group should latter decide if these requirements are acceptable.

Table 6.4 Example of system requirement table.

Nr	**Requirement on the system**
S1	The floor elements should be reinforced in the top at the supports
S2	

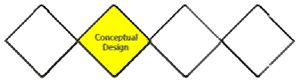
6.2.2 Definition of connection

- Implement basic conditions from the system definition that are decisive for the connection development and investigate how these basic conditions will affect the connection development process. This should preferable be done at the same time as the different activities are stated, in order to optimise the activities with regard to the basic conditions.

- Translate the system definition to requirements and criteria concerning the connection. Investigate how the requirements and criteria will affect the development process with a trial and error procedure before they are completely stated. Separate absolute requirements and evaluation criteria and include them in the tables. Assembly should be stressed in an industrial building system and is directly coupled to the connection development, and hence should the assembly be stressed at this early stage.

- Make a definition; a short text where the aim of the connection development is stated. State which evaluation criteria that are important.

6.3 Conceptual design



The aim with this activity is to produce a few connection concepts that agree with the earlier stated connection definition. The *conceptual design* activity is the most time consuming activity and most of the development work is going to be performed in this activity. It is likely that several system concepts are investigated. It is therefore convenient to perform a connection development process for every system concept.

- The fact that conceptual design is the biggest activity means that the activity needs proper planning. Divide the activity into sub-activities. It is preferable to state in which sub-activities information from the system development group is needed. For this development process the following eight sub activities are suggested:

    - *Brainstorming:* To find a lot of innovative solutions and not hinder creativity it is preferable to start with a brainstorming stage where all imaginable connection devices are welcome. It is not necessary that all ideas are good; a crazy idea may give birth to a good idea. The ideas that do not fit will be rejected later. Avoid searching for the "right" solution immediately. Inspiration can be gathered from other connections and other industries.

    - *Interpretation of the definition and the important requirements and criteria:* Try to make the important requirements and criteria, which are stressed in the definition, more concrete; what do the requirements mean in practice? In order to investigate how easy assembly could be divided into more concrete sub-criteria, *Connection design method* by Jürisoo and Staaf (2007) could be used. Investigate how the intended load path for the system affects the connections; which connection types are needed in order to take care of the loads? Information about the intended load path is needed.

    - *Elimination of solutions:* On the basis of the definition and the intended load path; reject the misaimed connection devices. The unrealistic connections should as well be rejected.

- o *Forming connection concepts:* Gather connection devices into connection concepts. A concept should be able to resist all loads that were stated in the *interpretation of the definition and the important requirement* sub-activity. Connection devices may be used in more than one connection concept.

- o *Improvements of the concepts:* Improve the connection concepts with regard to the absolute and evaluable requirements.

- o *Comparison between the connection concepts and the evaluation criteria:* Do a more comprehensive judgement of each criterion for each connection concept.

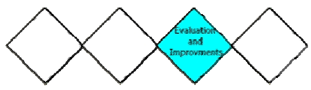
- o *Requirements on the system:* Decide what the system must fulfil if a particular connection device should be used. Communicate the requirements to the system development group by filling in the system requirement table (Table 6.4).

- o *Control of the absolute requirements and system requirement check:* Calculate how big force magnitudes the connection devices can resist. Assure that requirements on the system are fulfilled (Table 6.4). Load magnitudes and judgement of the requirement on the system is needed from the system.

- o *Concluding conceptual design:* Make sure that all decisions and tasks in the activity completion table (see Table 6.3) concerning conceptual design are fulfilled.

- It is important to emphasise that this activity is iterative; it is allowed to go backwards within the activity when a design is not sufficient.

6.4 Evaluation and improvements



The aim with this activity is to present one connection concept that should be delivered to the *detailed design* activity. The concept should be ready in such extent that the *detailed design* activity should give dimension and ranges for how the connections can be adopted in project development. This means that the concepts have to be evaluated and optimised in order to be able to select the most suitable concept. These two sub-activities may be repeated since iteration may be needed to be able to produce a connection concept that satisfies the aim with the activity.

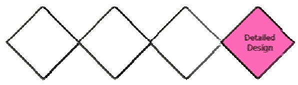
- Start the activity with a discussion concerning the different concepts and the definition. The conclusion should result in which criteria that should be evaluated.

- Decide how the aim with the activity should be reached, how should the connections be evaluated, which methods should be used etc. The evaluation methods should be more sophisticated the longer the activity reaches. For example, initially: simple drawings in combination with opinions from people with experience from design and assembly may be enough. Later in the activity a more sophisticated tool should be used. In order to evaluate easy assembly the evaluation tool in *Connection Design and Evaluation Method* (Jürisoo and Staaf, 2007) may be used.

- On the basis of the results from the evaluations try to improve the concepts in their problem areas.

- The evaluation methods should be more close to real life, e.g. virtual reality simulations, real life tests with the connection devices and full scale trials with elements included, when the concepts gets closer to their final design. Real life trials should be carried out in the latter stages of the activity and should work as an acknowledgement that the connection concept works as expected.

6.5 Detailed design



This activity aims to give the connection concept its final design and to state where and how the different connection devices should be used.

- State between which load magnitudes the different connections should be used.

- Implement the connections in different design systems for design of the different projects.

- Make the connection devices ready for manufacturing and project adaption

7 Case Study

In order to test the relevance in the earlier suggested guidelines for new development of connections it is necessary to simulate a case; how connection details in a building system should be developed on the basis of the method for connection design. The case study intends to describe how the development process will proceed if the guidelines, described in Chapter 6, are used. This case study is delimited to describe the content of the development process with regards to including activities and sub tasks that are directly linked to the connections. Other parameters that concern the development process such as group structure, time plan, organisation of meetings and risk analysis are not treated. Further on the system development's progress is considered to be carried out without any iteration though this might change the conditions for the connection development.

The connection details, a wall-to-floor, a wall-to-wall and a floor-to-floor connection, which the development process should result in, is described in Section 7.1 together with a system description. It is important to point out that the information presented in 7.1 is not known when the product development regarding connections is started. It is presented in order to give the reader an overview of the system when reading about the development process, which should ease the understanding of why certain choices are made.

In a real development process many solutions are invented, developed and rejected during the process until the optimal solution is found. This case study does, however, emphasise the process for the chosen connection. The connections that will be rejected during the process are only described briefly.

7.1 Building system description

The connection concept that is used in this case study is a part of a system, which is under development, by the company Consolis. Consolis is part of the European research project ManuBuild (see Section 1.1.3). The motive for the development of the system is to develop connections, in a concrete prefabrication system, which does not require complementary grouting. The incentive is to shorten construction time, since cast on-site contains time for hardening and an irrational assembly process.

All details and information about the building system are not known, since Consolis building system still is under development. The fact that all details and information are not known is not an essential issue for this case study since it aims to describe the development process with included activities and not the details in the system. Consolis building system is used as a tool to describe the process. Therefore, in order to be able to simulate the development process, unknown information about the system is assumed.

The load bearing elements, their details and intended structural behaviour are presented in Section 7.1.1-7.1.2. A principle sketch of a possible way to arrange the elements that are part of the building system is shown in Figure 7.1.

Figure 7.1 Principle sketch of Consolis building system, Consolis (2007).

7.1.1 Element descriptions

Intermediate floors: The floor-elements are made of pre-stressed concrete with bolted connections and are intended to work as one way slabs supported on load bearing walls (Figure 7.2). The floor elements also work as supports for wall elements (Figure 7.3), this restricts support rotation and the connection is considered to be partly fixed and a negative moment at the supports must be considered. Further on, the floor elements are part of the stabilising system, and function as diaphragms and are designed thereafter. The loads should be transferred between the floor elements by friction and by the connections themselves. The length of the floor elements can be freely chosen up to ten meters. The standard width is 2.4 meters. The thickness of the floor elements are set to 0.2 meters and load capacity is instead adjusted with reinforcement and degree of pre-stress. On top of the intermediate floor elements an internal floor is placed. The internal floor has room for installations; it is 15 cm thick and consists of light exposed aggregate and construction board on top.

Figure 7.2 Intermediate floor element supported on wall element, Consolis (2007).

Figure 7.3 Wall element supported on floor element, Consolis (2007).

Wall elements: There exists load bearing and non-load bearing walls both made of reinforced concrete with bolted connections. The thicknesses are 200 mm and 80 mm respectively. The wall elements are designed as sandwich type or joint free, when they are used as façades. The stability during assembly is solved by using special elements in the corners (Figure 7.4).

The shear forces between the elements can be transferred, as for the floor elements, with friction or through the connections only. The height of the elements is set to three meters in order to permit space for installations and sound insulation etc. and an inner storey height of 2.85 meters. The maximum length of the wall elements is ten meters.

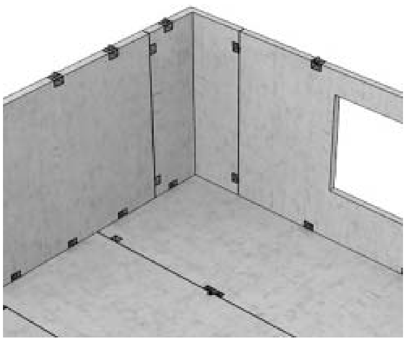


Figure 7.4 Special corner element, Consolis (2007).

7.1.2 Connection description

The main connection that is used in the building system can be used as floor-to-floor, floor-to-wall- and wall-to-wall connection. The connection devices, which are made of steel plates, are cast into the elements. The connection between the elements is solved by a bolt. A rubber sealing band should be placed between the elements in order to provide tightness. The rubber sealing should also transfer shear forces and compression forces. The connection devise is shown in Figure 7.5 when used in a floor-to-floor joint and in Figure 7.6 when used in floor-to- wall joints. To ease the assembly, without putting too big demands on tolerances when manufacturing the elements, the hole in one of the connection devices is made bigger then the bolt. The interaction between the bolt and the connection is solved by using a washer. To hide the devices in the walls a cover plate with the same colour as the wall is used. The floor elements are covered by an inner floor, which means that no further cover is needed where the connections are situated at the floor.

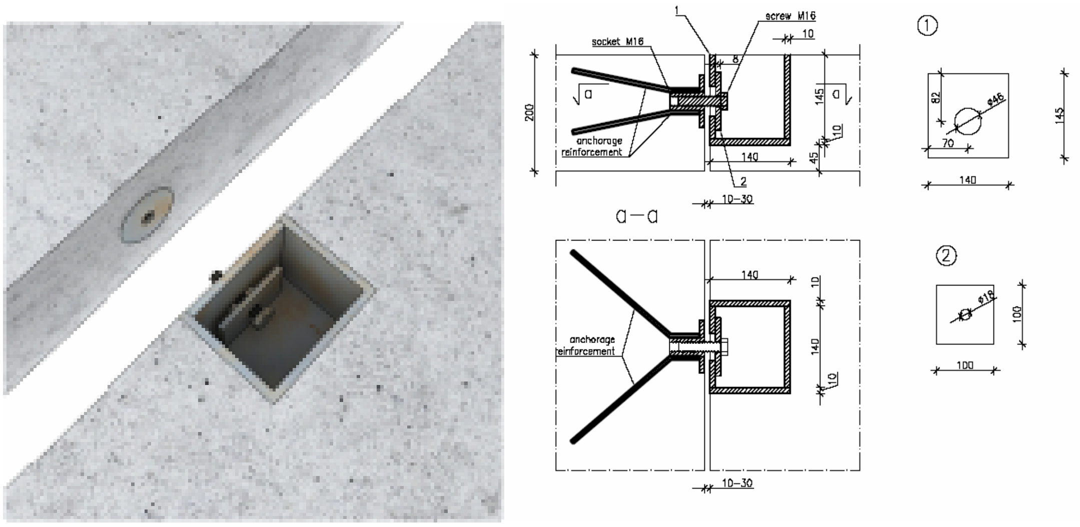


Figure 7.5 *Bolted floor-to-floor connection, principle sketch and detailed drawing, Consolis (2007).*

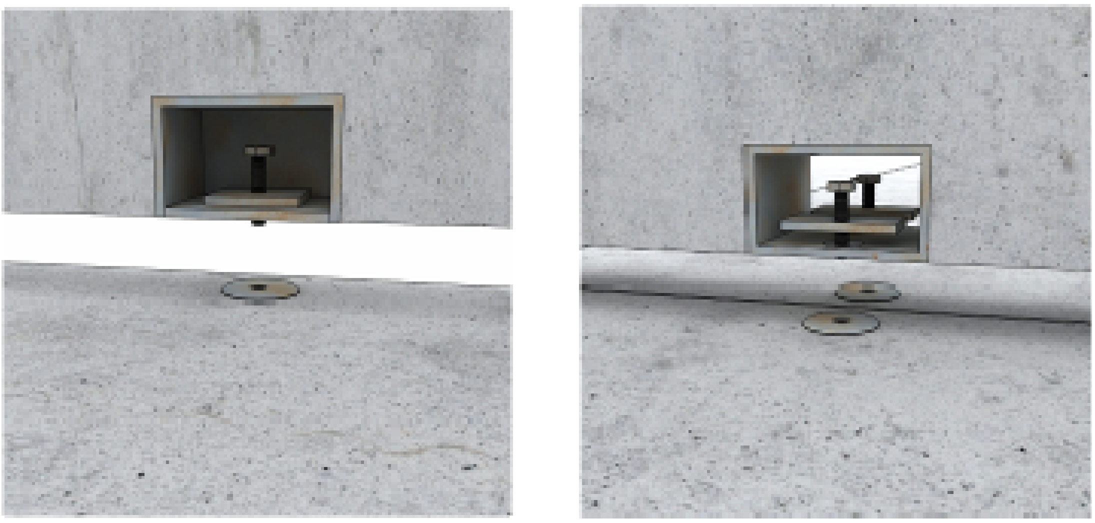


Figure 7.6 *bolted wall to floor connection with one and two floor elements respectively, Consolis (2007).*

In case of a high building an axial connection device must be used, in order to take care of the extra high shear forces. This connection devise works the same way as the original. The biggest difference is that a plate is used instead of a bolt to transfer the forces between the elements. The plate is bolted in both of the elements (see Figure 7.7).

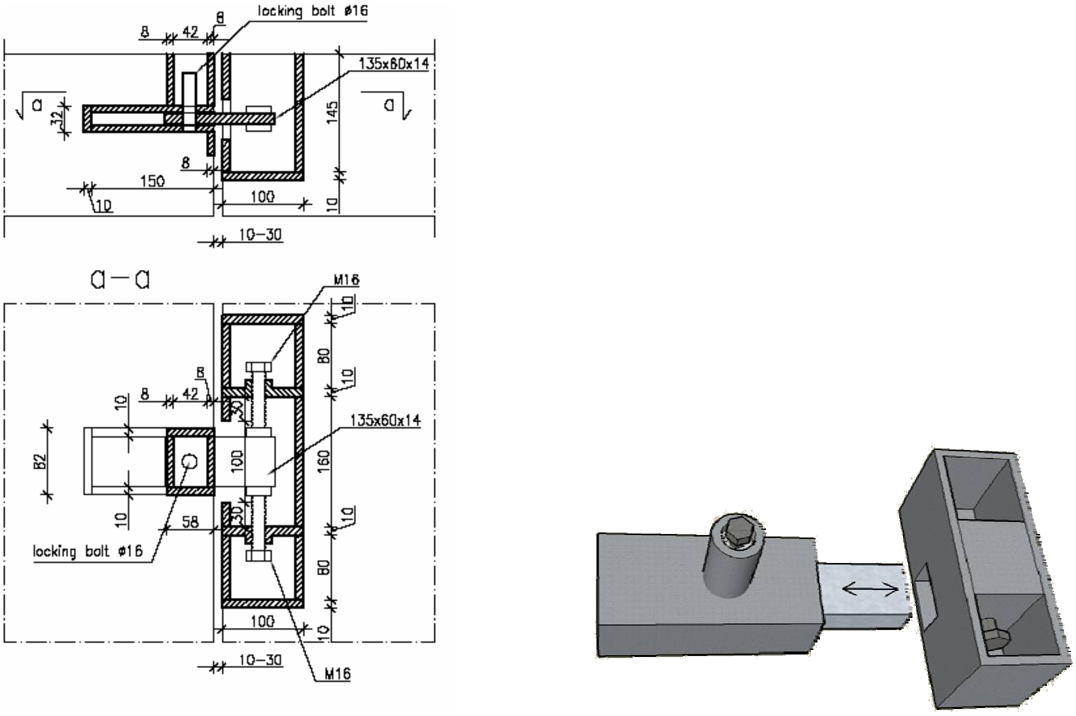


Figure 7.7 Detailed drawing and principle sketch of an axial connection, which is used in order to take care of large shear forces. (Consolis, 2007)

7.2 System definition – input necessary for connection development

As described in Chapter 3 a development process on system level precedes the connection development. In order to get a reasonable description of what the connection development process is based on, it is necessary to describe output from the preceding process. This chapter aims to describe what has been stated on system level from the system definition until the connection development is initialised.

The system is defined as follows, with the headlines from Section 3.1:

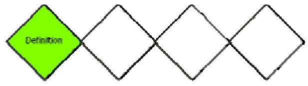
Project scope: Transportations within east of Europe, with a main focus in the vicinity of the factory.

Specifications of the target market: The houses that are built within the system are residential buildings and office buildings.

Product concept: The industrial process is emphasised in the building system, which results in high quality to a low cost. High flexibility should give the customer the opportunity to freely choose layout and aesthetics. The system should give priority to a high level of completeness to follow the industrial concept. The system should emphasise “sustainable development” thinking.

Product features, attributes and requirements: The number of stories is restricted to be less than eight, due to fire regulations. To be able to have a freedom to chose layout non load bearing partition walls are allowed in the system. Further on, the houses should keep a low profile in an architectural point of view, and they should not look like typical pre-fabricated houses with visible joints.

7.3 Connection definition



The first activity of the connection development is the definition. The activity contains a definition of the development process and a definition of the connection itself. This chapter follows the guidelines in Section 6.2. Parallel with this activity, activities that should result in other components, e.g. wall elements, goes on. It should be emphasised that the system definition has not prescribed any type of structural system yet. This means that several structural systems are investigated and hence several groups of connection concepts are handled, but not described.

7.3.1 Structure of the development process

The first thing to do, when the connection development starts, is to decide what the development process should contain.

A group is compound, with all necessary professions. All aspects described in the guidelines (Chapter 6) are considered when the group is formed.

Four activities are stated; *Definition, Conceptual design, Evaluation and improvements* and finally *Detailed design*. A time schedule is set up, where it is decided when the activities should begin and end. Further on, the aim with each activity is stated as well. *Definition*: defining which affects the system’s definition has on the connections. *Conceptual design*: Come up with a couple of concepts. *Evaluation and Improvements* select one concept. *Detailed design*: optimise and design the connection concept and make it ready for manufacturing.

It is decided that meetings should be held on weekly basis. In addition it is decided that all participants should keep a journal. They should also report there progression continuously to the project leader, who sets up a project report and delivers it to the whole group. All information should be treated through a web page, which is set up during this first activity.

Two documents are stated, where all requirement and criteria that effects the connection are set up; evaluation criteria (Table 7.1) and absolute requirements (Table 7.2). These tables will be further filled in during the development process. Assembly and load bearing capacity can be filled-in in this early stage since they are essential requirements and criteria.

Table 7.1 Evaluation criteria table concerning the connections, which should be further filled in during the process. Updates in the table are bold.

Nr	**<u>Evaluation criteria:</u>** Parameters:	Aim: The connection should…
E1	**Assembly**	**Allow a fast assembly of the elements**

Table 7.2 Requirement table for absolute requirements concerning the connections, which should be further filled in during the process. Updates in the table are bold.

Nr	**<u>Absolute requirements</u>** The connection should…	Fulfilled Yes/No
A1	**Be able to resist all applied forces**	

An activity completion table is set up (Table 7.3), in which it is explained what decisions and tasks that have to be made in order to conclude an activity. An activity can be concluded when all tasks and decisions concerning that particular activity are made. The aim of each activity can be filled-in in the table. It is also decided that the structural system should be set before the conceptual design can be concluded.

Table 7.3 Activity completion table, an activity can be concluded when all sub-tasks or decision are made, i.e. when the boxes of interest are market yes. Updates in the table are bold.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	
1	**The stated activities should be confirmed**	**X**		
2	**The structural system should be set before the conceptual design can be concluded**	**X**		
2	Come up with a couple of connection concepts		X	
3	Select one concept.		X	
4	Optimise the connection and make it ready for manufacturing		X	

7.3.2 Connection definition

Investigations and research work based on the system definition have resulted in basic conditions on system level. The basic conditions that are directly of interest for the connection development are presented here:

Type of system: The load bearing system should contain planar elements, in order to make the product easy to transport and allow flexibility. Depending on how the structural system will be solved the demands on the connections will vary, e.g. pinned or fixed.

Level of flexibility: The building system should have a standard wall height, element thickness and element width; the remaining measurements should be adjustable. The fact that the fixed parameters of the elements are the floor height, the element thickness and the element width means that the load variation on the connections will be big.

Multi functionality: Optimisation is not crucial, components should rather be possible to use in many cases and settings than be optimised for a certain case. This in combination with the level of flexibility aspect means that the connections should be designed so they can be adopted in a lot of different settings and positions of the system. The design will therefore be on the basis of the worst case scenario.

Fast assembly: Fast assembly is crucial for the connections, since the industrialised process is emphasised in the system definition.

Level of completeness: The system definition emphasises a high level of completeness of the elements when they are assembled. This excludes jointing methods that could pollute the elements, such as grouting and welding. This coincides with the fast assembly demand since grouting and welding are time consuming activities.

Functionality: The houses should be adoptable to both residential and office buildings. To be able to create an enjoyable environment for the tenants extra demands on the connections occur. These demands are, for example, concerning tightness with respect to sound, air-leakage and heat.

Accessibility: Inspection and maintenance of the components should be possible.

Environmental aspects: Sustainable development is considered in the system definition and hence it should be possible to demount the houses, thus should the connections be demountable. To get a sustainable house it is preferable to have possibilities for inspections and maintenance of the connections, i.e. the accessibility aspect is important for environmental reasons as well.

Architectural aspects: The system should allow different architectural solutions and the fact that the houses are prefabricated should not be obvious. Visible joints should therefore be avoided. The design should allow freedom for different inner planning solutions.

Economical aspects: Since the system's buildings should be as cheap as possible it is important to have a rational assembly process. Material prices and manufacturing methods are of course important but may have less importance than the assembly aspect. This since the connections are physically small relative the elements. Savings can of course be done with bigger quantities, which aligns with the multi functionality aspect.

These aspects from the system definition can be translated into a definition of the connections:

Connection definition

In addition to absolute requirement, like load bearing capacity, and function requirements, like tightness regarding air leakage, sound, heat and moisture the main focus in the connection design should be easy assembly. Other required features are: multi functionality, demountability and accessibility. Economical aspects should off course be considered in the development process. Fulfilling this connection definition, in as big extent as possible, is the aim of the development process.

The system is now interpreted and a connection definition is composed. The absolute and evaluation criteria are inserted in the tables (see Table 7.4 and Table 7.5).

Table 7.4 Requirement table for absolute requirements concerning the connections. The table should be further filled in during the process. Updates in the table are bold.

Nr	**<u>Absolute requirements</u>** The connection should…	Fulfilled Yes/No
A1	Be able to resist all applied forces and be designed according to valid codes and regulations	
A2	**Not convey welding or grouting on site**	

Table 7.5 Evaluation criteria table concerning the connections. The table should be further filled in during the process. Updates in the table are bold.

Nr	**<u>Evaluation criteria</u>** Parameters:	Aim: The connection should…
E1	Assembly	Allow a fast assembly of the elements
E2	**Tightness**	**Be tight against leakage regarding, sound, air, moisture and heat.**
E3	**Multi functionality**	**Be able to use in many situations**
E4	**Demountability**	**Be easy to demount**
E5	**Accessibility**	**Be easy to access**
E6	**Economy**	**Be cheap**
E7	**Visibility**	**Not be clearly visible**

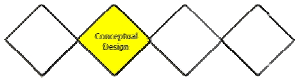
The connection definition, and the requirement and criteria tables, should give the connection development group a good starting point for conceptual design. It should be emphasised that the tables not are completed; every requirement and criterion should be divided into more specific sub-requirements or sub criteria. The lists are also going to be filled in with new requirements and criteria. The definition and the tables are approved by the system development group and the activity can therefore be concluded.

Further on, before the conceptual design can be initiated it is necessary to decide which system concepts that should be investigated. Every system concept corresponds to a connection development process and these processes proceeds parallel. This decision is inserted to the activity completion table (Table 7.6). The system development group decides that three different concepts should be investigated; load bearing concrete walls, steel frames with light walls and concrete walls with steel framing. All decisions and tasks concerning *activity 1* are made (see Table 7.6), and the activity can consequently be concluded.

Table 7.6 Activity completion table, an activity can be concluded when all sub tasks or decision are made, i.e. when the boxes of interest are ok. The table shows that activity 1 can be concluded. Updates in the table are bold.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	**Yes**
1	The stated activities should be confirmed	X		**Yes**
1	**It should be decided which system concepts that should be investigated**	**X**		**Yes**
2	Come up with a couple of connection concepts		X	
2	The structural system should be set before the conceptual design can be concluded	X		
3	Select one concept.		X	
4	Optimise the connection and make it ready for manufacturing		X	

7.4 Conceptual design



This activity's aim is to find a hand-full of promising solutions of how elements can be jointed together. It is important to have in mind that the conceptual design activity includes parallel development processes, as explained in Section 7.3.2. Each system concept, with the belonging connection, is treated as a unique development process. These concepts includes load bearing concrete wall and floor elements, steel frames with light walls and concrete walls with steel framing. However, this case study has been delimited to investigate only one of these concepts, concrete floor elements with load bearing concrete walls and the joining of these. This system concept involves a few different situations, wall-to-wall, floor-to-floor and floor-to-wall connections. In addition, it is different situations when, for example, walls should be connected with a horizontal or a vertical joint. Connection devices should of course be developed for all of these situations.

A planning of the *conceptual design's* sub-activities is made in this early stage of the activity. The planning includes which input and output to and from the system development group that is needed for the different sub-activities. The planning of the sub-activities is shown in Table 7.7. The conceptual design activity is iterative and the procedure can go backwards if requirements or criteria are not fulfilled. The sub-activities in Table 7.7 are further described in Section 7.4.1-7.4.9.

Table 7.7 Conceptual design is divided into sub-activities. The output and input that is needed for the different sub-activities are shown in the second column.

Sub-activity	**Output to or Input from the system**
Brainstorming	
Interpretation of the definition and the important requirements and criteria	Input: Intended load path
Elimination of solutions	
Forming connection concepts	
Improvements of the concepts	
Comparison between the connections and the evaluation criteria	
Requirement to the system	Output: Requirements on the system
Control of the absolute requirements and system requirement check	Input: Load magnitudes and judgement of the requirement on the system
Concluding conceptual design	Input: choice of five concepts

It is also decided that all connection devices that will go further to next activity, *Evaluation and improvements,* should fulfil the stressed evaluation criteria to a high degree and all of the absolute requirements. This is inserted to the activity completion table (Table 7.8).

Table 7.8 Activity completion table, an activity can be concluded when all sub-tasks or decisions are made, i.e. when the boxes of interest are ok. The table shows that three new tasks (bold) should be fulfilled in order to complete activity 2.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	Yes
1	The stated activities should be confirmed	X		Yes
1	It should be decided which system concepts that should be investigated	X		Yes
2	Come up with a couple of connection concepts		X	
2	The structural system should be set before the conceptual design can be concluded	X		
2	**The connections should fulfil the absolute requirements**		**X**	
2	**The connections should fulfil the stressed evaluation criteria to a big extent**	**X**	**X**	
2	**It should be confirmed that the requirement on the system are reasonable**	**X**		
3	Select one concept.		X	
4	Optimise the connection and make it ready for manufacturing		X	

7.4.1 Brainstorming

The connection development group starts with a brainstorming meeting and a discovering phase. The connections of interest in this system concept are floor-to-floor, floor-to-wall and wall-to-wall connections. The brainstorming phase does therefore concern all these connections. As a start for the conceptual design several non-detailed solutions on connections are sketched. In this stage the quantity is more important than the quality; solutions that may seem “crazy” are accepted in order to allow creativity. This brainstorming will of course generate solutions that not correspond to the connection definition and they can therefore easily be rejected. Others can be rejected since the solutions are not realistic to solve in practise. However, the idea with the brainstorming is to allow innovative thinking, which may lead to something totally new. If a standard connection, which has been used before, is most suitable after all it will be shown later in the process. The result of the brainstorming is visualised in Figure 7.8. Inspiration for these connection concepts has been gathered from existing connections as well as from other areas than building construction.

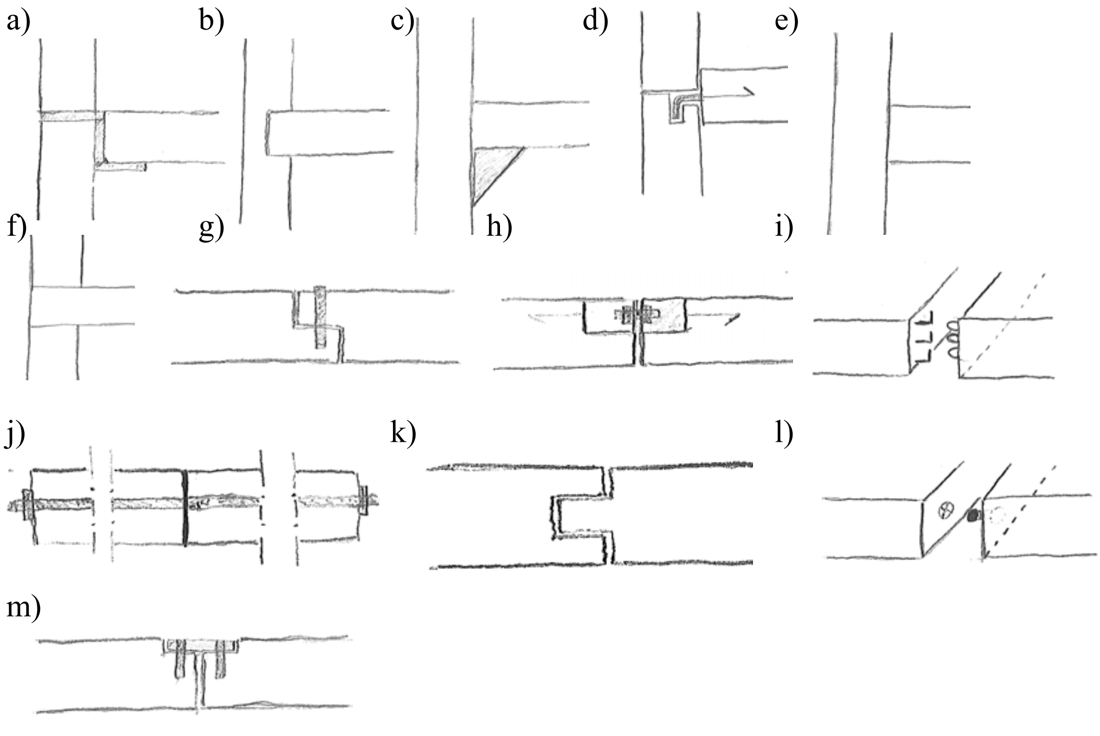


Figure 7.8 Connection devices invented in the brainstorming phase. a) z-profile b) Recess in element c) Cantilever support d) Hook e) Glue or Burdock f) Floor element between wall elements g)Bolted elements h) Screwed plates i) Hooked coils j) Post tensioned elements k) Recess in element l) Click connection m) Bolted steel plate.

7.4.2 Interpretation of the definition and the important evaluation criteria

The connections should, due to the definition, be easy to assemble. The connection development group does therefore check which criteria that has to be considered for a connection design that is easy to assembly. Jürisoo and Staaf (2007) have developed a method for how to design for easy assemble. The method contains sixteen criteria that should be evaluated. The criteria are presented in Table 7.9. The table functions as an appendix to the assembly criterion in the evaluation criteria table (Table 7.5).

Table 7.9 Criteria that should be consider in design for easy assembly, Jürisoo and Staaf (2007).

1a	Stability	Connections that provide stability fast and easy are preferred as the time needed for crane operations will be reduced.
1b	Positioning of Elements	Elements should preferably be guided into their final position.
1c	Positioning of Loose Parts	Loose connection details are preferred to be self guiding
1d	Number of Loose Parts	The loose connection parts needed during assembly should be as few as possible. In this case subassemblies are defined as one part
1f	Size of Loose Parts	Long or wide loose parts that are hard to handle should be avoided.
1g	Weight of Loose Parts	Heavy loose parts should be avoided.
1h	Need for Assembly Workers	The need for assembly workers should be minimized. Every operation should preferably be performed by only one worker (except crane operator). No special skills, e.g. welding skills, of the workers should be needed.
1i	Safety for Workers	The risk for workers getting injured in the assembly process because of the connection should be minimized.
1j	Tools	Heavy, large or cumbersome tools should be avoided and the number of tools should be kept low.

1k	Accessibility	Connections should be accessible for the workers at assembly if needed. Avoid to place connections in tight sections or outside at high levels.
1l	Fixation Method	Fasteners should be designed as simple as possible. Snap fits are preferred in comparison with screws while complex connections such as welding, grouting and other wet connections should be avoided.
1m	Protruding Parts	It is important that connections are not fragile or harmful to components, protruding parts, other connections and personnel.
1n	Multi-Purpose Connections	Try to integrate lifting devices in the connection. The elements should hang straight when lifted.
1o	Fool Proof	It should preferable be impossible to perform a misassembly. For example parts should only be possible to assemble in a certain position and screws should not be possible to fasten too hard or too loose.
1p	Demountability	Elements should be possible to demount without getting damaged.
1q	Tolerance	Connections that are easy to adjust regarding tolerances are preferred.

In addition to the assembly criterion the system development group has come up with a concept concerning the intended load paths. This is of interest for the absolute requirement, load resistance, and should as well be considered in the initial evaluation of the connection concepts.

The intended load paths are delivered in sketches from the system development group and are presented in Figure 7.9 and Figure 7.10. Figure 7.9 shows the vertical load path. The floor-to-wall connection can be pinned or fixed. A fixed end connection sets more requirements on the connection. On the other hand, a fixed end connection allows larger span. It is decided that designing the connection as a fix end is too difficult since grouting is not allowed. Therefore, the connection should be designed as pinned. Furthermore, it is necessary to have interaction between the floor elements to assure that the floor elements function together as a slab element. Otherwise, one element can not spread the load to the adjoining elements and as a result local deflections may be too large if an element is subjected to a point load for example. This demands the connections to transfer shear forces in the vertical direction. Two approaches are found out, either by transferring the shear through the connections only or by using the connection to assure that friction between the elements can transfer the shear.

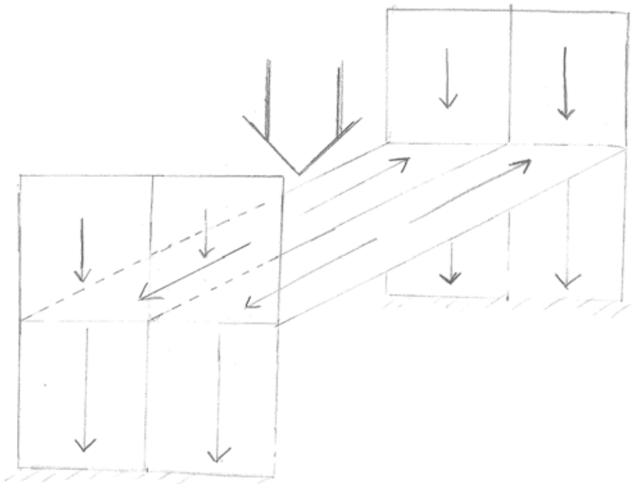
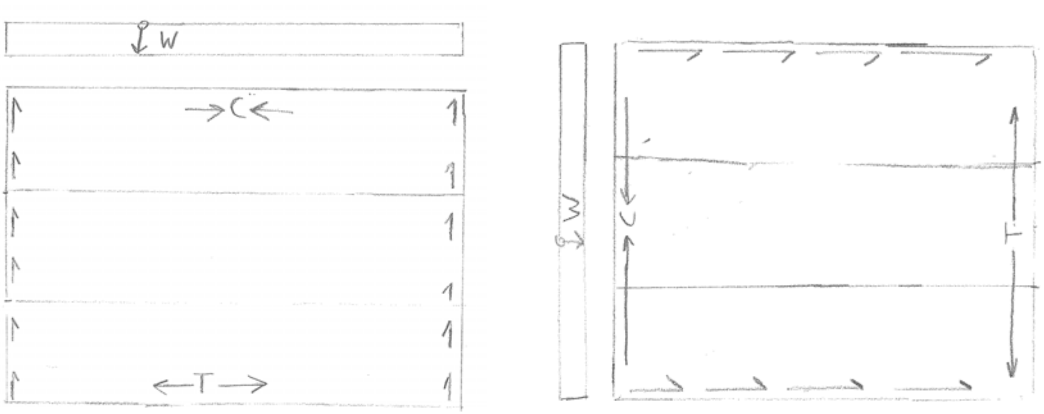


Figure 7.9 Principle sketch of how vertical loads are transferred to the foundation.

To stabilise the system two approaches are found. The first one is to take moment in the wall/floor connections, i.e. by the use of frame action. The moment forces are, however, going to be too large since the lever arm in an eight story building is about 24 meters, which is considered to be too much. The other approach is to transfer the horizontal forces to the walls that are going to function as shear walls. This does, however first of all demand the floor to work as a deep beam, which means that the connections should be able to take shear forces. This is, however, a demand that is already set due to the interaction between the elements, but in this case the shear flow is in the horizontal direction. More over, the connections must be able to transfer the loads to the walls with shear forces. Tension and compression forces occur since the floor works as a deep beam (Figure 7.10), which of course has to be considered.

In the load case that Figure 7.10 a) shows that the tension and the compression zones are in the length direction of the slab, which sets no requirements on the connections. The other load case is illustrated in Figure 7.10 b) where the tension and the compression forces are transferred between the elements. This demands that the connections should be able to transfer these forces.



a) b)

Figure 7.10 Principle sketch of force flow due to wind load, a) wind perpendicular to the floor elements and b) wind parallel to the floor elements.

The horizontal forces, should as mentioned above, be transferred from the floor elements to the wall elements that transfer them down to the foundation. This way of transferring the load can be explained as cantilever action, where many interacting wall elements are forming a cantilever beam. This cantilever action is illustrated in Figure 7.11.

When the walls are functioning as shear walls, tension and compression in the horizontal joints must be considered (Figure 7.11). Compression is not a real problem since the walls are made of concrete, which is very resistant to compression. The connections support area must however be of a certain size to avoid stress concentrations when compression is transferred into an element, i.e. disturbed regions must be considered. Vertical shear forces between the elements must also be considered in order to use the total width of the wall elements as the depth of the cantilever beam. All of these requirements are compiled in the absolute requirement table where the force types are specified (Table 7.10).

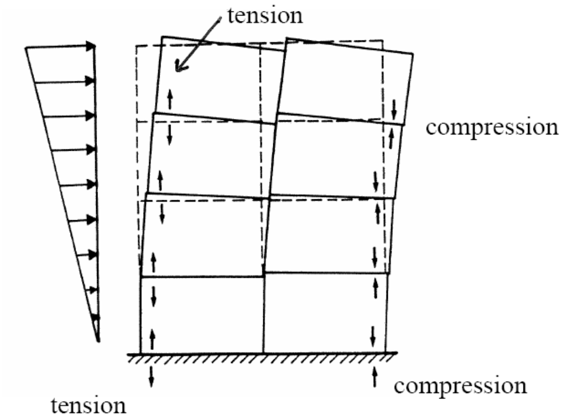


Figure 7.11 Principle sketch of force flow due to wind load, cantilever action, Fib (2007).

Table 7.10 Absolute requirement table concerning the connections. The table should be further filled in during the process. Updates in the table are bold.

Nr	**Absolute requirements** The connection should…	Fullfilled Yes/No
A1	Be able to resist all applied forces and be designed according to valid codes and regulations	
A1a	**Resist shear forces between floor and wall elements, i.e. between deep beam and shear wall, arisen from wind loads**	
A1b	**Lifting forces, between wall/wall or wall/floor depending on the connection design**	
A1c	**Compression forces between wall/wall or wall/floor depending on the connection design**	
A1d	**Resist shear forces between floor elements that transfers wind loads to the shear walls, between elements that are part of the deep beam**	
A1e	**Tension force between floor elements that are part of the deep beam. Assuming that the connections functions as flanges of the deep beam**	
A1f	**Compression force between floor elements that are part of the deep beam. Assuming that The connections functions as flanges of the deep beam**	
A1g	**Vertical shear force between wall elements**	
A2	Not convey welding or grouting on site	

7.4.3 Elimination of solutions

On the basis of the criteria from the assembly method (explained in Section 7.4.2) and from the absolute demands gained from the intended structural function the connection development group can easily reject a couple of solutions. After this elimination the connection development group has a couple of promising solutions left that can, or will after some changes, be able to fulfil the criteria and the absolute demands. The remaining connection details are shown in Figure 7.12.

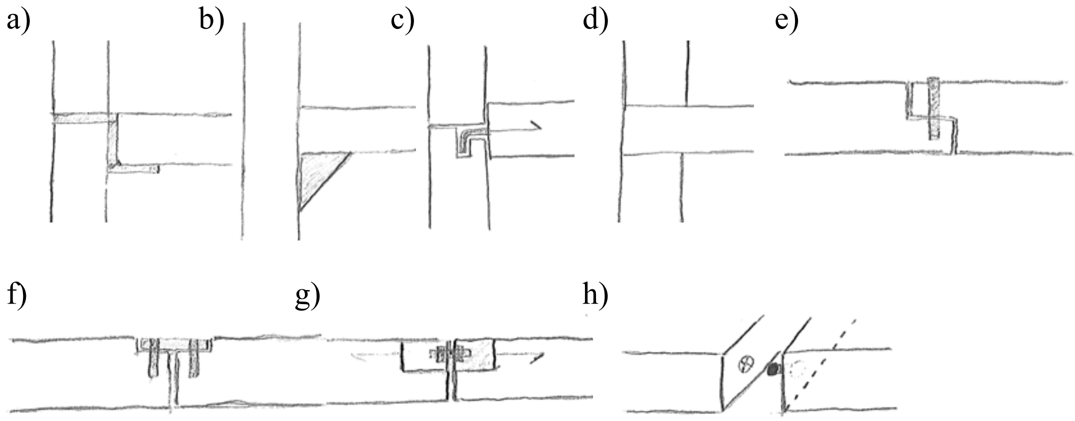
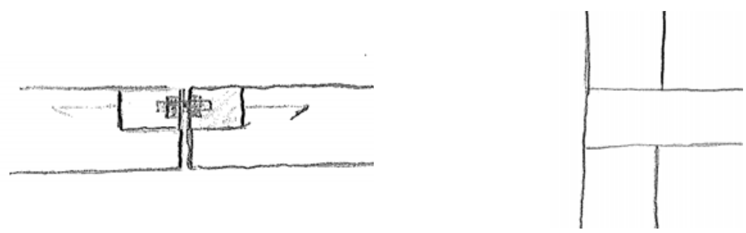


Figure 7.12 Connection concepts invented in the brainstorming phase and that are not rejected in the first elimination. a) z-profile b) Cantilever support c) Hook d) Floor element between wall elements e) Bolted elements f) Bolted steel plate g)Screwed steel plates h) Click connection

7.4.4 Forming connection concepts

Connection devices are gathered into connection concepts, which is able to resist all load situations in the absolute requirement table (Table 7.10). Several concepts are formed but only one is described in this case study. It should be mentioned that the devices can be used in several concepts. The chosen devices that form the concept are shown in Figure 7.13. The bolted steel plate (Figure 7.13 a) is intended to be used between floor elements and between wall elements in vertical joints. A combination of the two connections in Figure 7.13 is going to be used as wall-to floor connection.



a) b)

Figure 7.13 Concepts that should be further developed a) Bolted steel plate b) Floor element between wall elements.

7.4.5 Improvements of the concepts

On the basis of the absolute requirements and evaluation criteria each connection concept has to be improved. This section describes how one connection concept is developed; the connections, which where invented in the brainstorming phase, are shown in Figure 7.13. Other solutions are further developed as well, but the development of these concepts is not explained in this case study. The connection between floor and wall (Figure 7.13 b) must be improved in order to resist all loads. The idea is to have a similar solution as between wall elements and floor elements. The connection device in Figure 7.13 a) can be directly implemented to both the floor-to-floor situation and to the wall-to-wall situation where the joint is in vertical direction. A device suited as a wall-to-floor connection can be developed if the two connection device concepts in Figure 7.13 are combined. The improved connection devices are shown in Figure 7.14 and Figure 7.15. The connections can be considered as multifunctional since the same principles are used in both devices.

The modification of the floor-to-wall connection is, as shown in Figure 7.15, made by replacing one of the connection devices with a cast in nut. These connections' structural function is able to resist all forces in the absolute requirement table (Table 7.10). The magnitude of the forces is however not considered yet. It is therefore necessary to do investigation about force magnitudes.

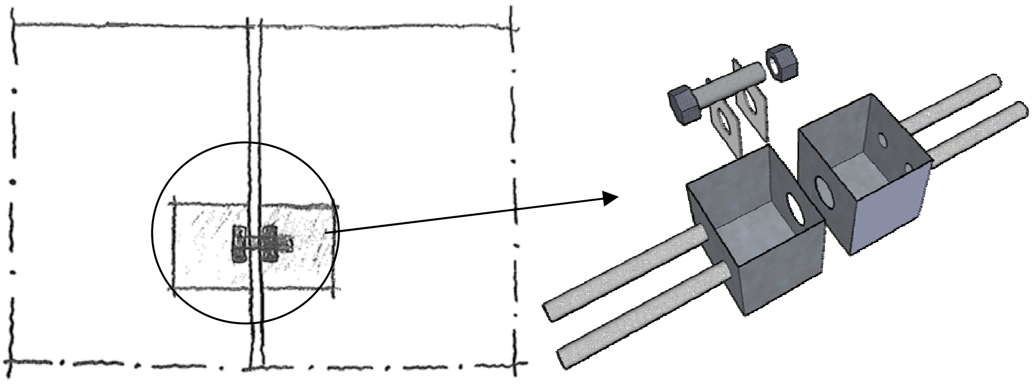


Figure 7.14 Sketch of floor-to-floor/ wall-to-wall connection. Visualised when cast in and the device only.

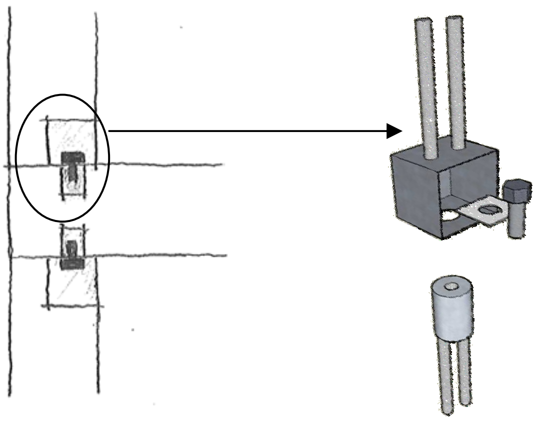


Figure 7.15 Sketch of floor-to-wall connection. Visualised when cast in and the device only.

7.4.6 Comparison between the connections and the evaluation criteria

The connection devices in Figure 7.14 and Figure 7.15 are now developed more detailed. The two devices are together considered as a connection concept. It is now time to check in which extent the connection devices fulfil the evaluation criteria.

Criterion 1, easy assembly is divided into several sub criteria, which is presented in an appendix (Table 7.9) to the evaluation criteria table (Table 7.10). The connection development group's opinion is that three sub criteria can be problematic in the continuing development concerning this connection concept, E1a) *Stability*, E1b) *Positioning of Elements* and E1p) *Tolerance*. The elements cannot surely be considered as stable and must therefore be provided with complementary bracings. The connection development group has, however, a suggestion that special corner elements can be used in order to provide stability and exclude superfluous work. *Positioning of elements* is also considered as hard to provide with the two connection devices. Wall elements get a clear guidance with help of, the earlier mentioned, special corner element. This method should ease the assembly. *Tolerance* is also a criterion that must be considered with extra caution in the continuing development. The connection can, however, provide some decreased demands on tolerances, since the washer allows bigger diameter of the hole than of the bolt, see Figure 7.14 and Figure 7.15. It is still hard to handle problems with progressive deviations caused by imprecise element dimensions.

Multi functionality is fulfilled since only two devices are used and both use the same principles. *Tightness* must be provided with supplementary work. *Accessibility* and *Demountability* are fulfilled if the connections are not going to be covered with for example an interior floor. *Economy* is mostly connected to easy assembly. *Visibility*: the connection must be covered in order to be invisible. The comments about the different criteria are written in the evaluation criteria table (Table 7.11).

Table 7.11 Evaluation criteria table concerning the connections. The table should be further filled in during the process. Updates in the table are bold.

Nr	**Evaluation criteria** Parameters:	Aim: The connection should…	**Comments**
E1	Assembly	Allow a fast assembly of the elements	**Special corner elements are beneficial concerning 1a) and 1b). 1c) Tolerances must be considered. See appendix, Table 7.9**
E2	Tightness	Be tight against leakage regarding, sound, air, moisture and heat	**Supplementary work**
E3	Multi functionality	Be able to use in many situations	**Fulfilled**
E4	Demountability	Be easy to demount	**Fulfilled if not covered**
E5	Accessibility	Be easy to access	**Fulfilled if not covered**
E6	Economy	Be cheap	**Connected to easy assembly**
E7	Visibility	Not be clearly visible	**Provided by a complementary cover**

7.4.7 Requirement to the system

The connection devices are now analysed with regard to the different requirements and criteria. In order to be able to use the connections requirements on the system have to be set. Some of the requirements are discussed in Section 7.4.5. The connection development group can therefore set requirement on the system.

First of all, the wall element is considered to be pinned, but the floor element is restrained to rotate since it is fixated between the two wall elements. Hence, a negative moment at the supports occurs and the floor elements must consequently be reinforced in the top at the end.

Since the connections are discrete an additional insulation along the elements is needed. This extra tightness requires supplementary work.

The cast in devices has also to be anchored in the concrete walls. This issue has to be considered of load transfer reasons and of manufacturing reasons. The steel plate surface should be in the same level as the element surface in order to avoid that compression forces will be transferred into the elements on a small area, i.e. the compression forces should be uniformly distributed along the element edge. This demands the elements to be fine and plain, which is tolerance and manufacturing requirements.

Further on, the connection types demand the element manufacturer and the manufacturer of the connection devices to have tight tolerances. The width and length of an element must be very exact. The connection can be designed in order to take care of small deviations by itself in order to make the element possible to assemble. Progressive deviations may be difficult to take care of, and tight tolerances are therefore demanded for the elements. High precision on the mounting of the devices in the elements is also demanded since the connection devices are going to be cast in the element.

The connection cannot assure stability during the erection, the walls must therefore be stabilised with help of additional bracings. This is unbeneficial with regard to assembly time. Another approach, which is better in an assembly point of view, is to have corner elements that are self stabilising, which the adjoining elements can stabilize against.

These requirements are delivered to the system development group with help of Table 7.12.

Table 7.12 System requirements set by the connection development group.

Nr	**System Requirements**
S1	The floor elements should be reinforced in the top at the supports
S2	Supplementary work for tightness
S3	Tight tolerances of element- width and length
S4	Anchoring of the devices must be considered
S5	Assure stability with help of special elements or bracings
S6	The elements surface must be fine to assure that compression forces can be resisted uniformly over an element
S7	The connections must be covered after assembly

7.4.8 Control of the absolute requirements and system requirement check

This stage of the conceptual design aims to check if the different concepts have potential to be used in the system. It is therefore time to assure that the absolute requirements can be properly fulfilled. Three results are possible after this stage; rejection, improvement or approval. If a connection concept is rejected it has no potential to fulfil the absolute requirements or it sets too hard requirements on the system. Improvement means that the connection has potential but must be improved. Approval means, of course, that the connection can go on to the next stage in the conceptual design.

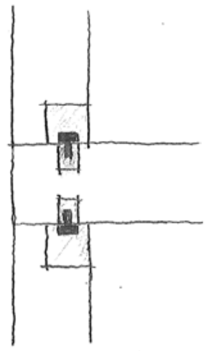
Since the connections should be designed according to worst case scenario, with consideration of the building system restrictions such as maximum building height and width, the largest magnitudes of load in each specific connection situation is delivered. The design loads are presented in Table 7.13. It should be emphasised that the load magnitudes in this case study are assumed.

Table 7.13 Requirement table for absolute requirements concerning the connections. The table should be further filled in during the process. Updates in the table are bold. All loads are assumed in this table.

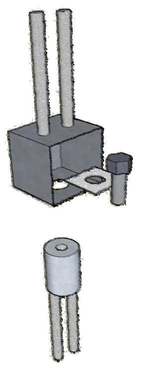
Nr	**Absolute requirements** The connection should…	**Load Magnitude**	Fullfilled Yes/No
A1	Be able to resist all applied forces and be designed according to valid codes and regulations		
A1a	Resist shear forces between floor and wall elements, i.e. between deep beam and shear wall, arisen from wind loads	**775 kN**	
A1b	Lifting forces, between wall/wall or wall/floor depending on the connection design	**10 kN**	
A1c	Compression forces between wall/wall or wall/floor depending on the connection design	**20 kN**	
A1d	Resist shear forces between floor elements that transfers wind loads to the shear walls, between elements that are part of the deep beam	**775 kN**	
A1e	Tension force between floor elements that are part of the deep beam. Assuming that the connections functions as flanges of the deep beam	**48,5 kN**	
A1f	Compression force between floor elements that are part of the deep beam. Assuming that the connections functions as flanges of the deep beam	**48,5 kN**	
A1g	Vertical shear force between wall elements.	**100 kN**	
A2	Not convey welding or grouting on site		

Each requirement is investigated in order to see if the connections can withstand the load magnitudes. Rough dimensions of the connections are consequently stated. All calculations are based on worst case scenario.

Requirement A1a demands that the joint between the floor and wall element can resist shear forces. The connection type between floor and wall is shown in Figure 7.16. Calculations show that one connection device with help of friction between the elements and shear resistance in the dowel can withstand the load magnitude. In order to have perfect interaction a rubber sealing band is going to be attached to the elements. The calculations are based on following connection dimension; 10 mm plate thickness and 16 mm bolt diameter. Requirement A1b and A1c concern the same connection. The connection development group has already set a demand that the elements should be plain. The system has confirmed that the rubber sealing band, which is used to provide interaction between the elements, can be used in order to transfer compression forces as well. This means that the connection devices do not have to take care of the compression forces, the support area on the wall element is large enough. The lifting forces must though be transferred through the connection devices. To resist these tension forces a bolt diameter of 16 mm it is sufficient, i.e. the same connection dimension as in the shear force case is sufficient.



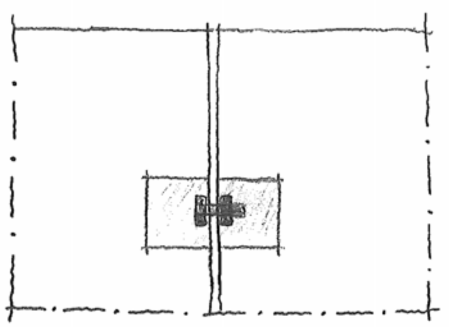
a)



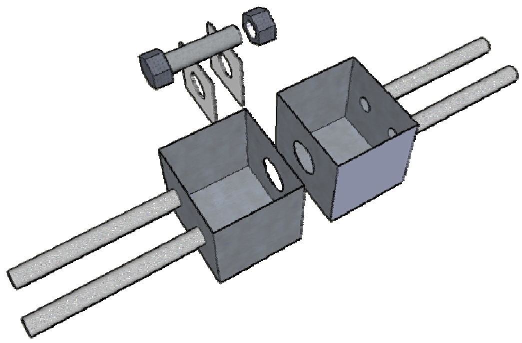
b)

Figure 7.16 Connection device between floor and wall.

Requirement A1d demands that the joint between floor and floor can resist shear forces. The connection type is shown in Figure 7.17. Since this joint is in the horizontal direction, the deadweight from the floor elements will not help to assure friction even though the rubber sealing band is used. The connection must therefore assure friction between the elements by themselves or be improved, so that the connection itself can transfer greater shear forces. The forces are, however, too big and the connection device must be redesigned or changed.



a)



b)

Figure 7.17 Connection device between floor elements and between wall elements vertical joint.

Requirement A1e treats the tension forces between the floor elements. The connection that will be used in this situation is shown in Figure 7.17. The connection will withstand the tension force with a bolt diameter of 16 mm and a plate thickness of 10 mm. To transfer the tension into the concrete element two reinforcement bars with a diameter of 16 mm are welded to the connection, see Figure 7.17. Requirement A1f demands the connection to withstand compression forces. The forces will be transferred through the rubber sealing band. The compression force will consequently be spread out over a bigger surface and the connections' function will be to assure contact between the elements. The compression forces can otherwise be transferred in the wall that is not intended to transfer compression forces. The floor element can transfer these compression forces. Requirement A1g concerns the same connection device, but in this case it is placed in the wall elements. The connection assures interaction between the elements together with the rubber sealing band, which means that shear can be transferred with help of friction.

After this check of the absolute requirements it can be concluded that all absolute requirement, except shear force between floor elements, can be solved by the two connection devices. It is therefore decided that a development of a special shear force connection should be initialised.

The system development group has received the requirement on the system, interpreted them and can therefore deliver an assessment of the requirements (Table 7.14). The system development group's opinion is that the requirements are reasonable. They do however consider that *the tolerances* can be a problem since concrete elements subjected to drying shrinkage. The result of the further development should show if the tolerances can be solved. More over, the system development group should investigate if special corner elements are a convenient method and if the method fits the system.

Table 7.14 System requirements set by the connection development group. Updates in the table are bold.

Nr	<u>**System Requirements**</u>	**Comment from system development group**
S1	The floor elements should be reinforced in the top at the supports	**Ok**
S2	Supplementary work for tightness	**Solved by an additional rubber sealing band**
S3	Tight tolerances of element- width and length	**May be a problem**
S4	Anchoring of the devices must be considered	**Ok**
S5	Assure stability with help of special elements or bracings	**Special corner elements should be considered in the system development.**
S6	The elements surface must be fine to assure that compression forces can be resisted uniformly over an element	**Provided by a additional rubber sealing band**
S7	The connections must be covered after assembly	**Ok**

Shear Force Connection Device – Iteration of Conceptual Design

This section has described that the shear forces between the floor elements where to large. It is therefore decided that the connection device should be improved. Since the process within the conceptual design activity is iterative the process starts over again. The connection devices that can transfer the forces they are subjected to must not go through the process again. It is the floor-to-floor connection that should be improved. It should be emphasised that the existing floor-to-floor connection still can be used in cases where the force is not that large and the same device is used in vertical wall-to-wall joints. Since the process in conceptual design is already described in this case study the new shear force device is presented without a presentation of the development process.

The shear force connection device consists of a steel plate that is connected to both floor elements. Before assembly the steel plate is stuck in one of the elements. When the elements are in right position the steel plate is inserted to the other one and it is then fixed to its correct position. A sketch of the shear force connection devices is shown in Figure 7.18.

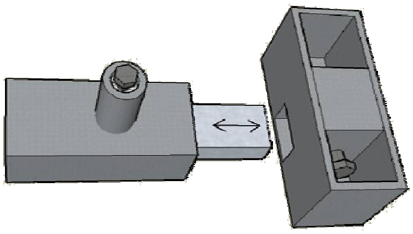


Figure 7.18 Connection device between floor elements, designed in order to resist big shear forces.

This connection device is only going to be used in case of a very high building, where the shear forces are big. The original connection is still used in the most cases in order to keep multi functionality criterion. The original connection is also considered as easier to assemble. The introduction of the shear force connection device conveys that all absolute requirements are fulfilled.

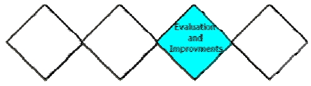
7.4.9 Concluding conceptual design

Before the activity is concluded the system development group checks the activity completion table. Five tasks or decisions should be made before the activity can be concluded. All of them are made and, hence the activity can be concluded. Five connection concepts are developed; all of them fulfil the absolute requirements and the stressed part of the evaluation criteria to a high degree. The system development group has confirmed that the requirements on the system, from all of the connection concepts, are reasonable. The system development group has also decided that the structural system should contain load bearing and stabilizing concrete walls and load bearing concrete floor elements. The activity completion table (Table 7.15) is therefore filled in.

Table 7.15 Activity completion table, an activity can be concluded when all sub tasks or decision are made, i.e. when the boxes of interest are ok. The table shows that activity 2 can be concluded. The updates in the table are bold.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	Yes
1	The stated activities should be confirmed	X		Yes
1	It should be decided which system concepts that should be investigated	X		Yes
2	Come up with a couple of connection concepts		X	**Yes**
2	The structural system should be set before the conceptual design can be concluded	X		**Yes**
2	The connections should fulfil the absolute requirements		X	**Yes**
2	The connections should fulfil the stressed evaluation criteria to a big extent	X	X	**Yes**
2	It should be confirmed that the requirement on the system are reasonable	X		**Yes**
3	Select one concept.		X	
4	Optimise the connection and make it ready for manufacturing		X	

7.5 Evaluation and improvements



The system development group has now decided that the structural system should contain concrete elements. The conceptual solution activity resulted in five concepts of connections for concrete elements. The connection development group should now evaluate these connection concepts and choose the most suitable one. All concepts fulfil the absolute requirements, and hence these requirements should not be considered in this activity. It is decided that the connections should be tested in real life before it is sent further to the next activity. This is inserted into the activity completion table (Table 7.16).

Table 7.16 Activity completion table, an activity can be concluded when the all sub tasks or decision are made, i.e. when the boxes of interest are ok. A new task concerning activity 3 is inserted (bold).

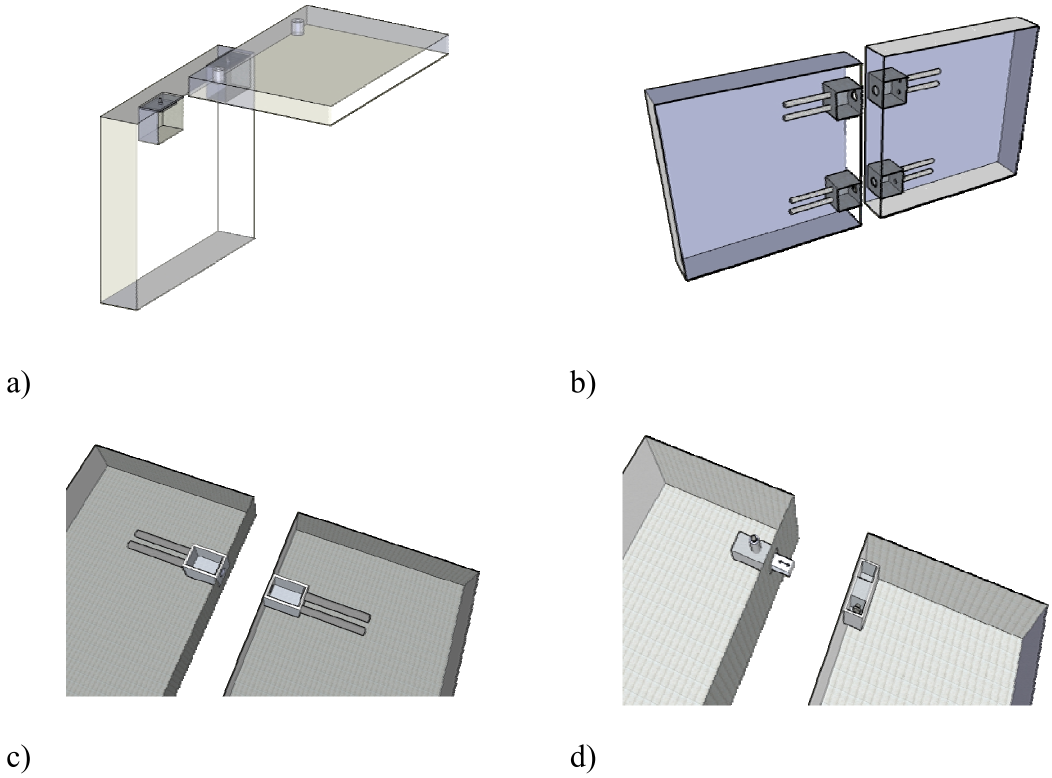
Activit y	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	Yes
1	The stated activities should be confirmed	X		Yes
1	It should be decided which system concepts that should be investigated	X		Yes
2	Come up with a couple of connection concepts		X	Yes
2	The structural system should be set before the conceptual design can be concluded	X		Yes
2	The connections should fulfil the absolute requirements		X	Yes
2	The connections should fulfil the stressed evaluation criteria to a big extent	X	X	Yes
2	It should be confirmed that the requirement on the system are reasonable	X		Yes

3	Select one concept.		X	
3	**A real life test should be performed**	**X**	**X**	
4	Optimise the connection and make it ready for manufacturing		X	

7.5.1 The evaluated connection concepts

This case study describes the evaluation of two of the five connection concepts, the procedure is, however, not different when more concepts should be evaluated. The first one (*connection concept 1*), whose development was described in Chapter 7.4, is shown in Figure 7.19. The second one is a developed z-profile connection (Figure 7.21), whose first sketch was presented in section 7.4.1. The z-profile connection (*connection concept 2*) has been developed in the same manner as *connection concept 1*. Both concepts contain the same connection devices in the floor-to-floor joint and in the vertical wall-to-wall joint. All included devices in the two concepts are presented in Figure 7.20 and Figure 7.22 respectively. The evaluation is carried out for one connection device at the time. The floor-to-wall connection device is evaluated for both concepts in order to decide which of the two concepts that is best suited in the building system. Since the two concepts contain the same wall-to-wall/floor-to-floor connection device, the evaluation of this device is not decisive for the choice of concept. Instead the aim of the evaluation is to identify areas that could be improved.

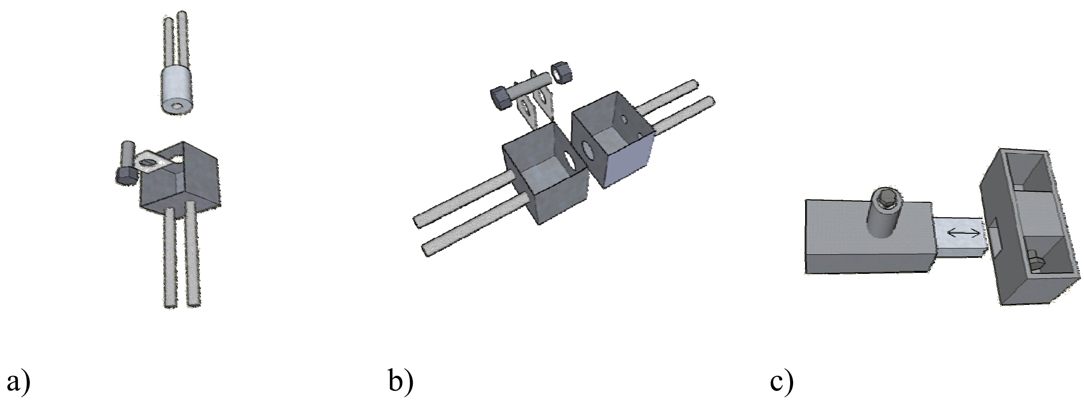
Connection concept 1



a) b)

c) d)

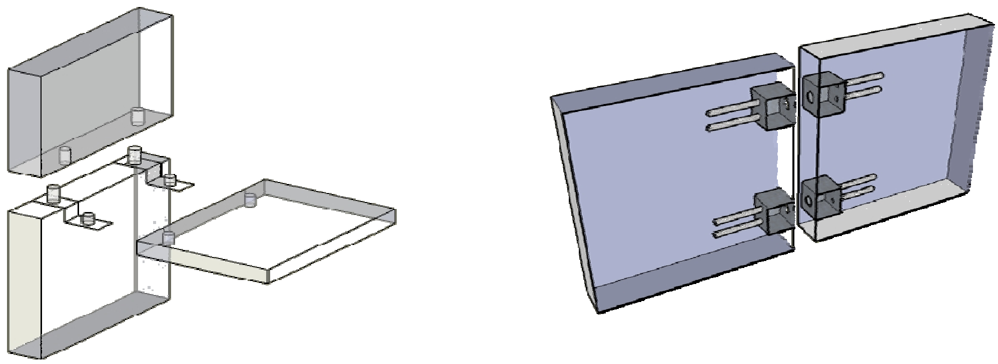
Figure 7.19 Connection concept 1 a) wall-to-floor b) wall-to-wall c) floor-to-floor d) floor-to-floor, in case of big shear forces.



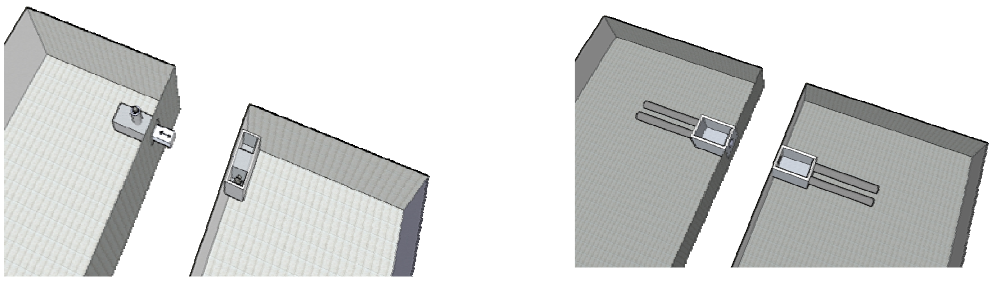
a) b) c)

Figure 7.20 Including connection devices: a) wall-to-floor, b) wall-to-wall/ floor-to-floor and c) floor-to-floor device in case of big shear forces.

Connection concept 2

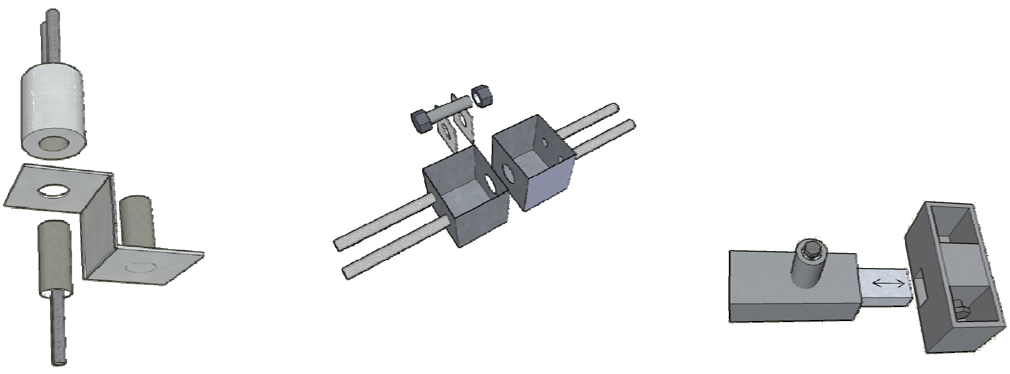


a) b)



c) d)

Figure 7.21 Connection concept 2 a) wall-to-floor b) wall-to-wall c) floor-to-floor d) floor-to-floor, in case of big shear forces



a) b) c)

Figure 7.22 Including connection devices: a) wall-to-floor, b) wall-to-wall/ floor-to-floor and c) floor-to-floor device in case of big shear forces.

7.5.2 Comparison of wall to floor connection devices

The first thing for the development group to do is to estimate what the evaluation criteria mean for each connection and to do a brief comparison. The criteria are presented in Table 7.17. The comments concern *connection concept 1* only. The comments that concerns *connection concept 2* are not shown. But a similar table exists and the differences between the two concepts are explained below. The connections of interest are shown in Figure 7.19 a) and Figure 7.21 a).

Table 7.17 Evaluation criteria table concerning connection Concept 1.

Nr	**Evaluation criteria** Parameters:	Aim: The connection should…	Comments
E1	Assembly	Allow a fast assembly of the elements	Special corner elements are beneficial concerning 1a) and 1b). 1c) Tolerances must be considered. See appendix, (Table 7.9)
E2	Tightness	Be tight against leakage regarding, sound, air, moisture and heat.	Supplementary work
E3	Multi functionality	Be able to use in many situations	Fulfilled
E4	Demountability	Be easy to demount	Fulfilled if not covered
E5	Accessibility	Be easy to access	Fulfilled if not covered
E6	Economy	Be cheap	Connected to easy assembly
E7	Visibility	Not be clearly visible	Provided by supplementary cover

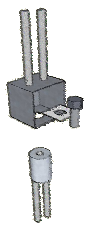
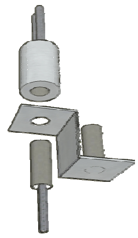
The most difficult criterion to evaluate is assembly. Evaluation of a connection concerning *Easy Assembly* requires a sophisticated method, and the connection devices are therefore evaluated with help of a *Connection Design and Evaluation Method* developed by Jürisoo and Staaf (2007). The easy assembly criteria that should be evaluated are presented in Table 7.9. The *Multi functionality* criterion can easily be judged since both the floor-to-wall devices are customised for the floor to wall joint. The *Multi Functionality* criterion can hence, not be considered as fulfilled. Both connection devices can be designed according to the worst case scenario, and hence they do not have to be compared further with regard to this criterion. *Tightness* in the joints should be provided with help of supplementary work and should therefore not be considered. The tightness in the connection itself must however be considered. Both connections are possible to *demount*, but the devices are going to be covered by an interior floor. The *accessibility* is therefore prevented and maintenance and inspections are therefore hard to perform. The connections are, however, placed in an indoor climate and are not exposed to any hazardous conditions. In worst case, if the connections are damaged, it is possible to access the connections if interior work is demolished. It is however positive aspects too, that the connections are no too easy to access. A person that does not have the right qualifications should not be able to access a connection. Economy is mostly decided due to the connections' ability to ease the assembly process. It is estimated that the z-profile is cheaper, since it is a standard profile, concerning the price for manufacturing the connection devices themselves.

This means that the connections are quite similar in most of the aspects. Differences exist in the multi functionality and economy criteria. In addition *Easy Assembly* should be further evaluated.

7.5.3 Evaluation of easy assembly for floor-to-wall connection devices

The assembly criterion is not properly investigated yet and since assembly is emphasised in the definition it is likely that this criterion is decisive. The connection development group makes a judgement of the assemblability with help of *Connection Design and Evaluation Method (*see Section 7.5.2*)*. The floor-to-wall connection devices are initially evaluated. The evaluation is mainly performed in order to find the most suitable connection device but also to see in which areas improvements can be made.

Table 7.18 Evaluation between the two wall-to-floor connection devices, Jürisoo and Staaf (2007).

	Device 1				Device 2		
	NUMBER OF CRITERIA USED	15			NUMBER OF CRITERIA USED	15	
	MEAN GRADE	1,87			MEAN GRADE	1,61	
	INDEX	72%			INDEX	65%	
Criteria	**Importance**	**Point**	**Grade**		**Importance**	**Point**	**Grade**
Stability	0	-	-		0	-	-
Positioning of Elements	1	-1	-1		1	3	3
Positioning of Loose Parts	1	-1	-1		1	3	3
Number of Loose Parts	2	1	2		2	3	6
Size of Loose Parts	1	3	3		1	1	1
Weight of Loose Parts	1	3	3		1	-1	-1
Need for Assembly Workers	2	3	6		2	3	6
Safety for Workers	1	1	1		1	1	1
Tools	2	3	6		2	3	6
Accessibility	1	3	3		1	3	3
Fixation Method	2	1	2		2	3	6
Protruding Parts	2	3	6		2	-1	-2
Multi-Purpose Connections	2	1	2		2	-1	-2
Fool Proof	1	3	3		1	3	3
Demountability	2	3	6		2	3	6
Tolerance	2	1	2		2	-1	-2

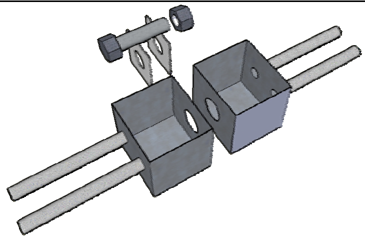
The evaluation shows that the two connection devices are quite similar with respect to easy assembly index. The cast in steel connection have, however, a better index, which indicates that it is a little bit easier to assemble. The z-profile (*Connection concept 2*) will therefore be rejected. The floor to wall device in *Connection concept 1* has two obvious problem areas where the grades from the evaluation are low; the positioning of elements and the positioning of loose parts criteria. The importance factors of the criteria are however low. The positioning of elements will be solved since special corner elements are used to assure the stability during assembly. Since the corner elements provide the elements stability, the assembly must start from them and the elements position will thus be solved gradually. The loose parts of the connection device are not self guiding. It is estimated that there will occur no mentionable extra assemble time due to lack of self guiding. The positioning of loose parts criteria is therefore not considered as a crucial problem.

The connection device will be further tested with real life models in order to investigate assemble times etc.

7.5.4 Evaluation of easy assembly for floor-to-floor-/wall-to-wall connections

The floor-to-floor/ wall-to-wall connection device is also evaluated in the same manner with the help of the *Connection design Method.* The evaluation is performed in order to improve the design with regard to the easy assemble criterion. As mentioned in Section 7.4.8 a special shear force connection has been developed. The special connection has been developed for situations where the shear forces are extra large; in all other cases the connection, which is described here, is used. The evaluation and the improvements of the special shear force connection are however not described in this case study.

Table 7.19 Evaluation table concerning easy assembly for floor-to-floor/wall-to-wall connection device.

	**Floor-to-floor/wall-to-wall Connection**		
NUMBER OF CRITERIA USED		15	
MEAN GRADE		1,70	
INDEX		67%	
SUMMARY OF CRITERIA			
Criteria	**Importance**	**Point**	**Grade**
Stability	0	-	-
Positioning of Elements	1	-1	-1
Positioning of Loose Parts	1	-1	-1
Number of Loose Parts	2	-1	-2
Size of Loose Parts	1	3	3
Weight of Loose Parts	1	3	3
Need for Assembly Workers	2	3	6
Safety for Workers	1	1	1
Tools	2	3	6
Accessibility	1	3	3
Fixation Method	2	1	2
Protruding Parts	2	3	6
Multi-Purpose Connections	2	1	2
Fool Proof	1	3	3
Demountability	2	3	6
Tolerance	2	1	2

The positioning of the elements and the positioning of loose parts are scored low in this evaluation. The same reasoning as mentioned for the floor to wall connection device is valid for this connection device as well, i.e. special corner elements are used and the loose parts are not considered to cause extra assembly time. In addition to these criteria the number of loose part criteria is scored low. The importance factor is here a bit higher due to the fact that extra parts to assemble are time consuming. The design is therefore revised before real life testing is initialised.

The *Connection Design Method,* developed by Jürisoo and Staaf (2007), contains a part reduction section (see Figure 7.23) whose aim is to minimize the parts without loosing functionality. In order to minimize the included parts of the floor-to-floor connection the part reduction test is performed.

MINIMIZE THE NUMBER OF PARTS USING THE FOLLOWING QUESTIONS		
Answer the following questions for each part in the connection. If all questions concerning a part result in negative answers, the studied part could be eliminated or combined with another part.		
Question	**Yes**	**No**
Does the part move relative all other parts?		
Must the part be of another material than other parts?		
Must the part be separated from other parts, or else one or more of the other parts' assembly will be impossible?		

Figure 7.23 Part reduction formulary from Jürisso and Staaf (2007) Connection Design and Evaluation Method.

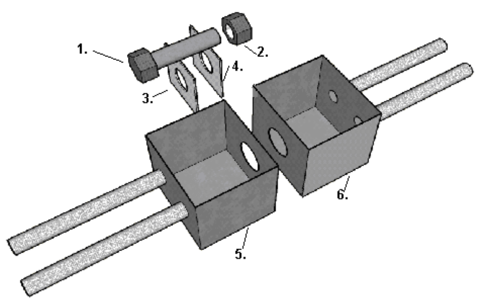


Figure 7.24 Connection device, floor-to-floor and wall-to-wall.

After the part reduction is performed on the connection device in Figure 7.24 it is clarified that part 2, 3, 4 and 6 can be eliminated or combined with another part. The solution is that part 3 should be combined with part 1. Part 2, 4 and 6 should be combined to one part. The function of part 2, 4 and 6, when combined, is the same as for the female part of floor-to-wall connection (see Figure 7.25), i.e. it should resist shear, tension and compression forces. It is therefore possible to optimise the connection by replacing part 2, 4 and 6 with the female part of the floor-to wall connection. The difference is that the load magnitudes are bigger for the floor-to-floor connection. The connection device is therefore checked with the load magnitudes of the floor-to-floor connection. This change does also align with the multi-functionality criterion, since the connection device will be adoptable in all connection situations. The combination of part 1 and 3 can of course also be used in the floor-to-wall connection. The result after the combination of part 1 and 3 and the replacing of part

2, 4 and 6 with the floor-to-wall connection is shown in Figure 7.25 The result of the part reduction in the floor-to-wall connection is shown in Figure 7.26.

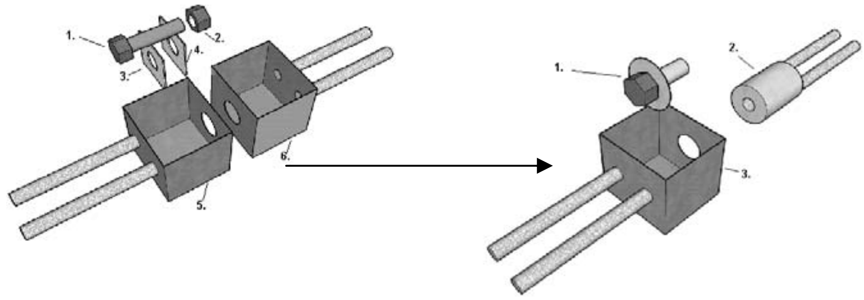


Figure 7.25 Sketch of floor-to-floor/ wall-to-wall connection, before and after part reduction.

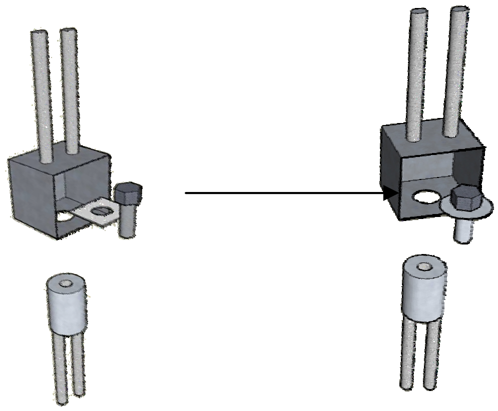


Figure 7.26 Sketch of floor-to-wall connection, before and after part reduction.

As visualised in Figure 7.25 and Figure 7.26 the result of the part reduction is one connection device which is adoptable in all connection situations (except for the case where the shear force is exceptionally large).

7.5.5 Testing

In order to confirm that the connection development has resulted in a connection concept that in reality corresponds with the connection definition, full scale models of the connection devices are manufactured. This is also an acknowledgement of that the connection concept can be manufactured. The connection devices are initially tested without the elements to make sure that the connection design does not have any obvious defects. Finally the connection devices are tested together with the elements in order to see the real function, with regard to assembly time etc.

The tests of the connection concept in this case study correspond to the aim with the design and the concept is therefore delivered to the final design activity.

7.5.6 Concluding the activity

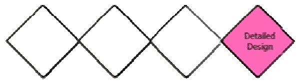
In order to conclude this activity the connection development group checks the activity completion table. It shows that all decisions and sub-tasks that concerns activity 3, evaluation and improvements, can be filled with yes. The activity can consequently be concluded.

Table 7.20 Activity completion table, an activity can be concluded when all sub tasks or decision are made, i.e. when the boxes of interest are ok. The table shows that activity 3 can be concluded (bold).

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and criteria	X	X	Yes
1	The stated activities should be confirmed	X		Yes
1	It should be decided which system concepts that should be investigated	X		Yes
2	Come up with a couple of connection concepts		X	Yes
2	The structural system should be set before the conceptual design can be concluded	X		Yes
2	The connections should fulfil the absolute requirements		X	Yes
2	The connections should fulfil the stressed evaluation criteria to a big extent	X	X	Yes
2	It should be confirmed that the requirement on the system are reasonable	X		Yes

3	Select one concept.		X	**Yes**
3	A real life test should be performed	X	X	**Yes**
4	Optimise the connection and make it ready for manufacturing		X	

7.6 Detailed design



The aim with this activity is to give the connection concept its final design and give directives for how the connection concepts should be adopted in project development; when should which connection device be used?

The directives, which are worked out by the connection development group, are implemented in computer programs which should ease the work for the designers while developing a project. The computer programs should on the basis of input, such as house geometry, load magnitudes, geographical position etc. present the number of connection devices and where they should be placed.

7.6.1 Main connection device

The main connection device that is developed can be used as floor-to-floor, wall-to-wall and floor-to-wall connection. The connection device has, after more detailed calculations, got its final design and measurements. The detailed drawing is shown in Figure 7.27.

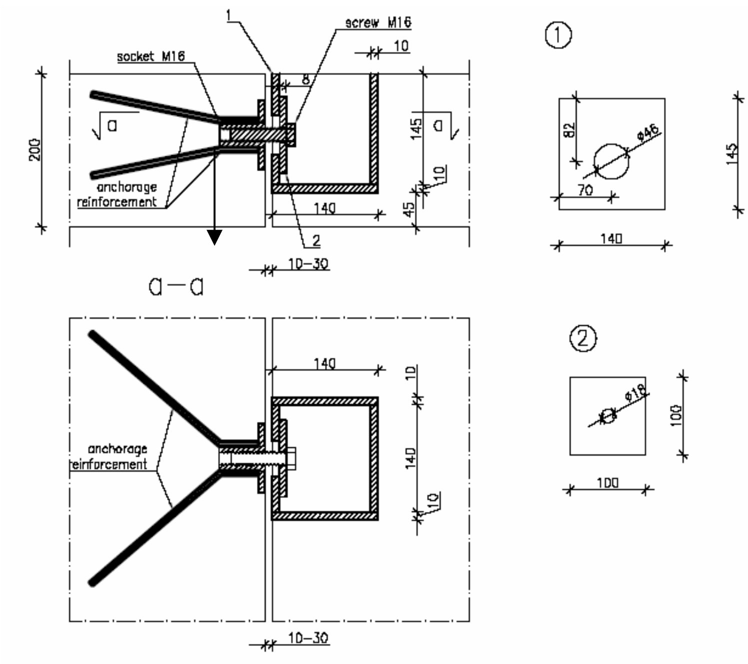


Figure 7.27   Detailed drawing of the main connection device, Consolis (2007).

7.6.2 Shear force connection device

The shear force connection device is developed in order to resist big shear forces, and should only be used in situations when the shear force is too big for the main connection device. The final design of the shear force connection device is presented as detailed drawings in Figure 7.28.

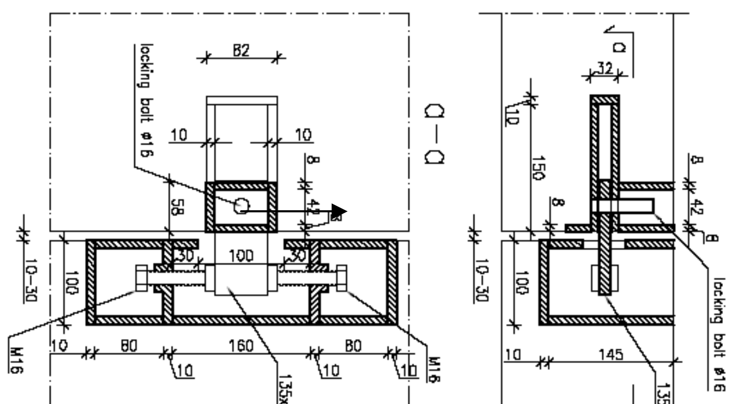


Figure 7.28   Detailed drawing of the shear force connection device, Consolis (2007).

7.6.3 Concluding the activity

This last activity can be concluded when all decisions and tasks concerning the *detailed design* activity is fulfilled. This is shown in Table 7.21. This means that the development process can be concluded.

Table 7.21 Activity completion table, an activity can be concluded when all sub-tasks or decision are made, i.e. when the boxes of interest are ok. The table shows that the activity can be concluded.

Activity	Description	Approved by		Approved
		System	Connection	Yes/No
1	Defining the aim with the connection development, important requirements and conditions	X	X	Yes
1	The stated activities should be confirmed	X		Yes
1	It should be decided which system concepts that should be investigated	X		Yes
2	Come up with a couple of connection concepts		X	Yes
2	The structural system should be set before the conceptual design can be concluded	X		Yes
2	The connections should fulfil the absolute requirements		X	Yes
2	The connections should fulfil the stressed evaluation criteria to a big extent	X	X	Yes
2	It should be confirmed that the requirement on the system are reasonable	X		Yes
3	Select one concept.		X	Yes
3	A real life test should be performed	X	X	Yes
4	Optimise the connection and make it ready for manufacturing		X	**Yes**

7.7 Conclusions of the case study

The aim with the case study was to ease the development, and to confirm the content, of the guidelines. It can be concluded that it would not have been possible to develop the guidelines without the case study, since complicated issues that need extra effort has been revealed while simulating the connection development. For example, how the system development and the connection group sets requirement on each other, and in which phase of the activities these requirements need to be communicated. It has also been clarified in which phase which information is needed. For example, before choices of connection concepts (all connections that are needed in a building, in order to transfer the loads to the ground) can be made the structural behaviour of the building must be known.

A disadvantage with the case study is that the system development group's progress has been assumed to be carried out without any iteration. This is unrealistic in a real development progress, since conditions changes and it is impossible to find the right solution from the beginning. This means that in a real connection development process information from the system may become revised and the process will go backwards, which is not described in this case study. The iteration on system level should however stay within the activities, in the same way as in the connection development. The activity completion table should be detailed in such extent that the activity is totally completed when the table is completed. This means that an activity completion table, in a real development process, must be more elaborated. Another difficulty in a real development process, which is impossible to simulate, is misunderstandings. Misunderstandings may aggravate and delay the development process. Further on, simulations of a real life test in the *Evaluation and Improvements* activity are not possible to describe in a detailed and realistic way. The test is therefore only mentioned briefly.

One issue that makes the development process difficult to describe in form of a case study is the fact that oral communication is very hard to simulate. Many decisions and much development work will be performed during meetings, formal or informal, in a real development process. It is also easier to explain requirements and evaluation criteria if some one does not understand. It should be emphasised that all decisions and all progress should be documented in a formal way even in a real development process.

8 Conclusions and Discussion of the Master's Project

The purpose of this Master's project was to facilitate the adoption of industrial thinking in the development processes in the building industry. The aim with this Master's thesis was to create a method for how to develop connections for industrial building systems. The method developed consists of clearly predefined activities with articulated breakpoints. A breakpoints means that all involved actors decides whether the process should proceed or not. A check should be made, which should give answers to the following questions: are all sub-aims fulfilled and is the main aim of the development process achievable? To a high degree, the new knowledge in this work consist of that the intuitive and creative activities are explicitly defined.

The approach, which includes predefined activities, will encourage planning of the development process and the development group will get clearly stated sub-aims. Planning of the process will help the developers to prioritise between different assignments and it is easier to focus on the right thing at right time. This means that the total resources are used effectively, which complies with the industrial thought. The method includes continuously reporting. One of the reasons for this is that a development group should do a follow-up after a completed project. This follow-up will support future development projects, which can be more efficient and resources could be even more effectively used.

The developed method contains predefined activities: *Definition, Conceptual design, Evaluation and improvements* and finally *Detailed design*. In the first activity are stated a *definition* of the development process and a definition of the important requirements and criteria on the connections. *Conceptual design* is the most time-consuming activity and when the most of the development work is performed. This activity results in a hand full of connection concepts. *Evaluation and improvements* aims to choose one of these. This activity should also result in improvements of the concepts. In the *detailed design* activity the connections should be prepared for manufacturing and be ready to be adapted in the projects.

Deciding to close a process can be more difficult than starting one. Therefore, in this method each activity is iterative but the whole development process is not. Between the activities there are articulated breakpoints. This means that when an activity has started it is not possible to go back to the previous one; the choice to initiate an activity is irreversible. In a breakpoint the developers should make sure that the quality of the developed product is as expected. The breakpoints do also function as a moment of afterthought; can the developed product gain profits or should the development project be stopped? The progress of the development process should be slow and the breakpoints allow evaluation of the accomplished work. Without breakpoints it is easy to go on with a process that was doomed from the beginning.

It has not been investigated how a real development group would have experienced a development process that is not iterative. Today developers are used to be able to go backwards in the process and recall decisions and redesign solutions. This is one of the reasons for the inefficiency of the construction industry. To change the way of thinking may be hard and time-consuming. Before developers get used to a slow progress that does not allow iterations the development process may lead to failed solutions. This means that gradual transition to non-iterative processes is needed.

This Master's thesis suggests that this way of dividing the development process in activities should be standardised. It must not specifically be the four activities that are presented in this Master's thesis, since every new project has different conditions and aim. This Master's project addresses connection development but the method's procedure can easily be adapted to development of other components in other parts of the construction industry. In that case, the requirements and evaluation criteria will of course be different. In addition, the idea of dividing the development process into activities may be implemented into other areas within building industry, for example development of a building system or a building project. Indeed, the idea for the connection development method origins from a method for architectural design. In the latter case, the suggested activities in this Master's thesis cannot be directly implemented, since other demands are set on the development process, such as investigations of customers' needs.

The method also includes non-static documents that should be updated as the development process proceeds. A thought from the beginning of the Master's project was to standardise for example requirement on connections, a part request form. The work has shown that it is hard, or even impossible, to predefine requirements that are valid for all connection types and situations. In addition, it may not even be desired due to the fact that it may lead to misaimed requirements and that important requirements are left out. It is therefore better to complete requirement and evaluation criteria documents as the process proceeds and new information is known. This also makes the developers more alert and they must think about consequences of set requirements and criteria and how things are related to each other. This Master's project suggests that the use of non-static document in development processes should be standardised. The document set-up should then be optimised for each new development process.

For further studies it is recommended by the authors that the method for connection development should be the foundation for a similar method for the development process of a building system. The connection development process treats several parts of the system development, since connections are a central part of the prefabrication industry, and to a large extent the developed method for connection development should be able to be used. The real development process of connections can be properly described only when it is a part of the system development process. It is suggested that the method should then be tested in a real development process. The method could then be evaluated and improved.

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