Implementing Virtual Design and Construction
Evaluation and improvement of the VDC implementation in the design phase of AEC projects

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Preface

This graduation report is the result of the graduation research which was performed for the Master Architecture, Urbanism and Building Sciences at Delft University of Technology. Performing this graduation research was a constant process of reflection and evaluation, which was characterized by moments of success and progression as well as moments of disappointment and setbacks. Support is essential to cross the finish line and therefore I would like to express several words of thanks.

First of all, I want to thank my girlfriend, Rianne. Your support and confidence has been of great value during my entire study. Of course I want to thank my parents for their continuous support during my study, which enabled me to get where I am today.

Moreover, I want to thank my mentors, Esra Bektas and Alexander Koutamanis for their professional guidance, insights and critical feedback. I also express my gratitude to Esra for sharing her research insights and case study data.

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Paul Schrama
Rotterdam, June 2011
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### Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AEC</td>
<td>Architecture, Engineering and Construction</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Model, Building Information Modeling</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>CDF</td>
<td>Concurrent Design Facility</td>
</tr>
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<td>CIFE</td>
<td>Center for Integrated Facility Engineering</td>
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<td>DTM</td>
<td>Design Team Meeting</td>
</tr>
<tr>
<td>DWG</td>
<td>Drawing, exchange format for CAD drawings</td>
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<tr>
<td>EM</td>
<td>Engineering Meeting</td>
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<tr>
<td>FD</td>
<td>Final Design</td>
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<tr>
<td>GEC</td>
<td>Global Engineering Center</td>
</tr>
<tr>
<td>ICE</td>
<td>Integrated Concurrent Engineering</td>
</tr>
<tr>
<td>IFC</td>
<td>Industrial Foundation Classes</td>
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<tr>
<td>MEP</td>
<td>Mechanical, Electrical and Plumbing</td>
</tr>
<tr>
<td>PD</td>
<td>Preliminary Design</td>
</tr>
<tr>
<td>PDF</td>
<td>Portable Document Format, exchange format for digital information</td>
</tr>
<tr>
<td>PIM</td>
<td>Process Interface Map, Process Interface Management</td>
</tr>
<tr>
<td>POP</td>
<td>Product, Organization, Process</td>
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<tr>
<td>PoR</td>
<td>Program of Requirements</td>
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<tr>
<td>RFI</td>
<td>Request For Information</td>
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<tr>
<td>SSC</td>
<td>Shared Services Center, company-wide facilities department</td>
</tr>
<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
</tr>
<tr>
<td>VDC</td>
<td>Virtual Design and Construction</td>
</tr>
<tr>
<td>VDT</td>
<td>Virtual Design Team</td>
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<tr>
<td>XC</td>
<td>Extreme Collaboration</td>
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Management summary

Design processes in the Architecture, Engineering and Construction (AEC) industry are claimed to lack performance (Churchill and Thoren, 2009; CIB, 2009; Rezgui et al, 2009). The lacking performance is caused by fragmentation of the industry into multiple disciplines (Rezgui et al, 2009). As a result of the multi-disciplinary nature of the industry, integrated collaboration is becoming increasingly important. However, integrated collaboration appears to be challenging as a result of characteristics of the AEC industry, such as the project-based nature, short-term business relationships and adversarial culture (Anumba et al, 2005 cited in Bektas et al, 2010a; Farinha et al, 2007; Churchill and Thoren, 2009). Throughout the AEC industry, initiatives are undertaken to improve performance of the AEC design process.

Initiatives such as Integrated Project Delivery (IPD) and Integrated Design and Delivery Solutions (IDDS) are focused on increasing integrated collaboration within design teams, through a combination of technological developments, alternative business models and a focus on organization and process (AIA, 2007; CIB, 2009). Whereas IPD and IDDS describe rather theoretical visions, a design approach called Virtual Design and Construction (VDC) is focused on operational aspects to translate those visions into practice. VDC provides integrated, multi-disciplinary, performance based virtual design and construction modeling (Garcia et al, 2004). VDC consists of several components, which focus on the level of the Product (the design), Organization (the design team) and Process (the design process) (POP) (Kunz and Fischer, 2009). POP visualizations are applied to visualize product, organization and process, whereas POP metrics are used for performance measurement. Theory describes that the VDC components are applied during an Integrated Concurrent Engineering (ICE) process, which takes place in an interactive meeting room.

Although VDC is claimed to increase performance through integrated collaboration, VDC theory is still developing. Moreover, implementation of VDC is currently limited to case study projects and pilot environments in the US. Although companies in the Netherlands have identified VDC as a promising design approach for large AEC projects, the actual implementation of VDC in such projects is unclear. Therefore, this research aims to determine the expected degree of VDC implementation during the design phase of large, real-life projects. Moreover, this research aims to identify how VDC implementation in such projects can be improved.

The research was conducted at a Dutch engineering consultancy firm which is currently implementing VDC. The research consisted of an extensive literature study about VDC and two case studies. The first case study was a pilot project during which VDC was applied. This case study was used to identify the current implementation of VDC during a pilot project. The other case study was a large, real-life AEC project. This case study provided insight into the project characteristics and challenges which are found in current, non-VDC practice. Data for the case studies was collected by means of semi-structured interviews with actors from different levels of the project organization. Additionally, observations and documentation analysis provided insight into the design processes of
both case study projects. A cross case-theory analysis was performed to identify the influence of project characteristics of large AEC projects on the implementation of VDC. Moreover, challenges of large AEC projects provided insight into the need of VDC implementation.

The research results show that in general, implementation of VDC during the design phase of large AEC projects is expected to be limited. The VDC case study showed that VDC components were only partially applied during the pilot project. VDC implementation in large AEC projects will be even more difficult as a result of additional project size, complexity, duration and actor involvement. The research showed that implementation of VDC in large AEC projects is expected to be limited to basic POP visualizations and POP metrics. Integrated Concurrent Engineering is expected to remain limited as well. Although application of more profound POP modeling, POP metrics and Integrated Concurrent Engineering is expected to be a long term goal, the current achievable level of VDC implementation could already provide some improvement of design process performance.

Further VDC implementation in large AEC projects is expected to require a significant amount of effort, because of the large gap between VDC and the traditional design approach. Moreover, the added value of additional VDC implementation is yet unknown. In order to decrease the gap and to define the added value, it is recommended to use pilot projects. Pilot projects offer interaction between theory and practice. As such, pilot projects are important for the development of VDC theory as well as the improvement of VDC implementation in practice. Implementation of VDC in large AEC projects should be considered as a gradual process which consists of small steps.
1. Research introduction

This chapter serves as an introductory chapter to the graduation research. Goal of this chapter is to provide insight into the outline of the graduation research. First, the research backgrounds are briefly described. Secondly, a section about the research outline describes the problem statement, aim and relevance and main questions for the research. The methodology section describes the research method and ways of data collection. Finally, a brief readers guide provides an overview of the report contents.

1.1 Research backgrounds

Collaboration in the Dutch Architecture, Engineering and Construction (AEC) industry is characterized by a multi-disciplinary nature. In the past, engineering was divided into few main disciplines, whereas today many disciplines and sub-disciplines exist (Garcia et al, 2004; Huijsmans, 2009). Actors from all of these disciplines focus on a specific part of the design and construction of a building and need to work together in multi-disciplinary design teams in order to achieve the development of a qualitative building within time and budget. The AEC industry is identified as underperforming and currently, the industry is focused on increasing integrated collaboration (AIA, 2007; CIB, 2009; Kunz and Fischer, 2009).

The Center for Integrated Facility Engineering (CIFE) from Stanford University initiated the development of a specific integrated design approach: Virtual Design and Construction (VDC). The VDC approach aims to improve and increase multi-disciplinary design team collaboration by using visualization and performance measuring of not only the design, but also the organization and the design process (Kunz and Fischer, 2009). Although the VDC approach is still developing, VDC was applied in several projects in the US AEC industry. Currently, two Dutch companies have started with using the VDC approach as well.

1.2 Research outline

1.2.1 Problem statement

The start of the development of the VDC approach by CIFE Stanford University dates back for several years. Nevertheless, VDC is still developing (Kunz and Fischer, 2009). Case studies about the implementation of VDC have been performed. Most of these case studies have taken place in US AEC industry and were conducted by researchers from CIFE (Garcia et al, 2004; Khanzode et al, 2008). Currently, several Dutch AEC companies have recognized the VDC approach as a promising design-construction approach and are implementing VDC in their AEC projects. Although these companies
identified possible benefits of VDC, the companies experience difficulties when implementing VDC theories in practice.

DHV, a large Dutch based consultancy firm, is one of the companies which are currently implementing VDC. Two employees attended the VDC certificate course program at CIFE, Stanford University, which is a program to train AEC professionals in VDC use. Also, an iRoom (interactive meeting room with three presentation touch screens and computers) was installed at the DHV office in The Hague. Recently, DHV started a VDC pilot project to experiment with the implementation of VDC. This pilot project was a real project, however it was a project of limited size which was carried out in a limited project environment which is different from usual project environments. During this pilot project, implementation difficulties were experienced. However, VDC is claimed to improve the design and construction process (Garcia et al, 2004; Kunz and Fischer, 2009). Therefore, companies want to try to implement VDC in large, real-life AEC projects. Research is necessary to determine the current status of VDC implementation. Moreover, research should show the next steps to take to reach further implementation of VDC in large, real-life projects in practice.

1.2.2 Aim and relevance

This research aims to provide insight in the current status of VDC implementation in pilot environments. Moreover, this research aims to identify to what extent VDC can be implemented in large real-life AEC projects in practice. Therefore, this research not only focuses on the pilot project in which VDC was applied; the research also aims to provide insight into the influence of characteristics of current traditional (non-VDC) projects on VDC implementation. The result of the research can be used for further scientific research with regard to VDC and related fields of research. For example, the research shows to what extent the VDC approach is implemented in practice and what problems or difficulties are experienced when the VDC approach is applied during the design phase of AEC projects. In other words, the research aims to identify fields for future research into VDC and VDC implementation, which could help to build and improve VDC theory. Besides scientific contributions, the results of the research can be used by companies in the Dutch AEC practice which are working or planning to work with VDC. The research provides these companies with practical recommendations and points of attention with regard to VDC implementation.

1.2.3 Research questions

The research focuses on answering the following main research question (MRQs):

MRQ1: To what extent can VDC be implemented during the design phase of large Dutch AEC projects?

MRQ2: How can the implementation of VDC in the design phase of large Dutch AEC projects be improved?
1.3 Research methodology

1.3.1 Conceptual framework

The research aim and research questions demand an exploratory research approach. Therefore, this research is based on qualitative case study research combined with a literature study, as shown in figure 1.1. The theory about the VDC approach was analyzed and organized, resulting in a theoretical framework. This theoretical framework provided an overview of the components of the VDC approach and the purpose of these components. This overview was used as a framework for description and analysis of the design approaches used during both case study projects. Two case studies have been performed. Both case studies are about projects in which the graduation company was involved.

![Diagram](image)

*Figure 1.1: Conceptual framework*

The first case study was a pilot project which was initiated by DHV to experiment with the implementation of VDC. This VDC case study shows the current implementation and current use of VDC during the design phase of an AEC project in the Netherlands. Findings of the VDC case study are analyzed with respect to the theory about the VDC approach, which will provide insight into the VDC implementation status in Dutch AEC practice. However, the VDC case study project was performed in a limited pilot environment. For example, a limited amount of external actors and organizations were involved. Moreover, the project size, duration and complexity were limited as well. In other words, the VDC pilot project provides limited insight into the expected implementation of VDC in large, real-life projects.

Nevertheless, VDC is claimed to provide possibilities for increasing performance of larger and more complex projects (Kunz and Fischer, 2009). Companies such as DHV have identified these possibilities and aim to use VDC in such projects. Therefore, a second case study was used, which was a large and complex AEC project. This case study identified the current non-VDC approach used during the design phase of a large, real-life AEC project and showed the situation and characteristics of such a project. Such insight shows how the VDC implementation might be limited or encouraged by the characteristics of large real-life AEC projects.
For the non-VDC case study, a project was selected which was not experimental, meaning that it was not a pilot project. The selected case study project was developed for an external client. Having an external client means that the design team has less direct control and interaction with regard to the client. Moreover, a project for an external client is likely to have more strictly limited resources such as project budget, project duration and project goals. Besides that, the client of the non-VDC case study project was organized in different organizations, adding to overall project complexity. In addition to that, the project selected for the non-VDC case study was developed by a multi-disciplinary design team with actors from different organizations. In other words, actors have different company goals which might possibly contradict, which provides a reliable representation of the situation in practice. Moreover, interaction between the actors within the design team is somewhat limited as a result of organization boundaries. Also, the non-VDC case study project had a project organization with multiple levels in the project hierarchy, which adds boundaries between the project levels as well. All of these project characteristics might influence the implementation of VDC in real-life, large AEC projects.

A cross case-theory analysis between the theoretical framework, the VDC case study and the non-VDC case study was performed to analyze the VDC implementation. The cross case-theory analysis showed the status of implementation of VDC in the pilot project. Besides insight into the current implementation status, the cross case-theory analysis also identified how further VDC implementation might be influenced by characteristics of current AEC projects. Finally, the research results in recommendations for future research and recommendations for improvement of VDC implementation.

1.3.2 Data collection

Data for the theoretical framework was obtained from an extensive literature review. In addition to the theory derived from literature, use was made of knowledge of the two DHV employees who followed the VDC certificate course program at CIFE, Stanford University. Besides conversations with these employees, consultation with CIFE professors via these employees was possible, which provided additional understanding of VDC which in turn was used for the development of the theoretical framework.

Data for the case studies was collected using several methods. First, interviews with project actors of both projects were conducted. In total, fourteen interviews were conducted with an average interview duration of 70 minutes. The interviews were held using a semi-structured layout, which provided some structure for the interview and at the same time offered freedom to change focus during the interview when needed. Moreover, additional interview data for the non-VDC case study was available, through the PhD research of Esra Bektas at Delft University of Technology. The diagram in appendix I provides a detailed overview of all interviews used for the research.

Second, multiple ways of observation were applied. For the non-VDC case study, video recordings made for the PhD research of Esra Bektas were available. These video recordings identified the approach used during meetings of the non-VDC project. The video observation was combined with observation of design team meetings of another project to gain additional insight into non-VDC meetings. For the VDC case study, a video recording of a conference call was available which was
used to identify how digital tools were used to communicate during the design phase. Although no meetings for the VDC pilot project took place during the research period, insight into the usability of the iRoom was gained through observation of two iRoom meetings of other projects and through interviews with two iRoom users. Finally, daily observation at the office of the graduation company provided insight into the daily practice at an engineering consultancy firm in the AEC industry. Besides interviews and observation, project documentation was made available for the research. An important type of project documentation used for the research are minutes of the meetings which were held for the case study projects. These minutes showed the type of issues addressed during meetings. Additionally, the minutes showed how information was captured during meetings. A second important source of information were emails. For both case studies, the emails send or received by the department of structural engineering were made available. For the VDC case study, the emails send or received by the DHV project managers were available as well. The emails provided insight into the project process in between the meetings. Finally, other project documentation such as project directories, plannings, images, videos, presentations, memo’s and project kick-off documents provided insight into the design approach.

Insights derived from the different types of data were combined to get a complete overview of the design approaches applied during the case study projects. As such, the combined data provided insight into the use of VDC during the VDC pilot project as well as the design approach and project characteristics of the non-VDC project.

### 1.4 Readers guide

This chapter described the general research outline. The next chapter will describe the theoretical framework in more detail. Chapter 3 and 4 describe the case studies about the VDC pilot project and the non-VDC project. Subsequently, the cross case-theory analysis is described, followed by conclusions and discussion in chapter 6. The report finishes with recommendations for future research and recommendations for improvement of VDC implementation in AEC practice.
2. Theoretical framework

This chapter describes the theoretical backgrounds of the research in more detail. First, the current design process and several main challenges, characteristics and developments are described. Second, the development of VDC is drawn, as well as the components of the VDC approach. Finally, views and experiences about VDC implementation are described.

2.1 Current design process in large projects in the AEC industry

2.1.1 Challenges in the AEC design process

The AEC industry delivers buildings and facilities which are used by everybody every day and as such, the industry has an important role in society (Hallberg and Tarandi, 2011). However, many researchers, stakeholders and companies state that design processes in the AEC industry lack performance and can be seen as inefficient (Churchill and Thoren, 2009; CIB, 2009; Rezgui et al, 2009). It is stressed that there is a need to increase quality of the building design and simultaneously decrease the cost and time necessary for AEC projects (CIB, 2009). In other words, the design process in the AEC industry is characterized by the challenge to increase performance of the industry. Throughout the scientific field as well as the industry itself, different causes of the lacking performance are mentioned.

Rezgui et al (2009) argues that the performance is limited by fragmentation within the AEC industry. This fragmentation means that multiple actors from different disciplines are involved in the design teams of projects (Bresnen et al, 2003; Anumba et al, 2005, cited in Bektas et al, 2010a). In other words, design teams in the AEC industry are characterized by a multi-disciplinary nature. Multiple disciplines and sub-disciplines have specific fields of expertise, deliver specific services and have specific individual goals. For example, the architectural firm delivers the architectural design, whereas engineering firms are specialized in the delivery of the structural design or installation design. The deliverables of all disciplines have to be combined into one design; hence, the design activity of all disciplines is interrelated.

The interrelation between the different disciplines results in a need for integrated collaboration within the design team. Garcia et al (2004) argue that performance of a project not solely depends on the expertise of individual professionals involved in the design team, but also on the extent to which these professionals are capable of working together. In other words, besides having excellent professionals involved in a project, integrated collaboration between disciplines is necessary to ensure a successful design process. Integrated collaboration requires alignment between the professionals involved. In order to reach such alignment, interaction between multi-disciplinary
professionals is needed, for example by means of communication and coordination (Garcia et al, 2004). However, interaction by means of communication within the design team is described as insufficient, resulting in misinterpretations and considerable amounts of rework (Bektas et al, 2010a). In short, integrated collaboration within the design team is often limited.

It is also stated that the design process in the AEC industry is project based (Anumba et al, 2005 cited in Bektas et al, 2010a), which results in temporary and short term business relationships between companies (Farinha et al, 2007). Others even describe the culture in the AEC industry as being adversarial (Churchill and Thoren, 2009). The absence of lasting business relationships makes it difficult to change the industry and improve overall integrated collaboration throughout projects.

Besides the issue of fragmentation, the AEC industry is characterized by a phased and iterative design process. Depending on the type of projects, the design process starts with conceptual design (CD) phase, followed by a preliminary design (PD) phase and a final design (FD) phase (Geraedts and Wamelink, 2009). Throughout the design process, the amount of available project information increases as a result of a continuous combination of design iterations. Simultaneously, the influence of the actors on the design is decreasing, as the design choices already made throughout the design process fix the design. In other words, there is a conflicting relationship between the availability of project information and the degree of project influence (Geraedts and Wamelink, 2009), as shown in figure 2.1.

![Figure 2.1: Conflicting relationship between project information and project influence, source: Geraedts and Wamelink (2009)](image)

This conflicting relationship between project information and project influence carries a specific risk for the AEC project. The client and the design team actors gain more insight into the design when the project progresses. In many cases this increased insight results in a refinement of the demands of the client as defined in the Program of Requirements (PoR). Such refinements are used to work out the design in more detail. However, the increased insight in the design process results in a need to change the Program of Requirements (PoR). Such changes of the requirements could cause a need for large design changes as well. When such large design changes occur, rework is inevitable and the project planning is at risk.

On the one hand, the performance of the AEC industry is under pressure as a result of the fragmentation into multiple different disciplines. On the other hand, the design process in the AEC industry is characterized by a phased and iterative process and a tension between project information and project influence, which limits performance. In other words, the AEC industry faces multiple challenges which have to be dealt with in order to increase the performance of the industry.
2.1.2 Developments in design processes in the AEC industry

In many countries, initiatives are undertaken by companies, stakeholders and researchers to improve the performance of the AEC design process (Farinha et al, 2007). These initiatives are mainly aimed at increasing integration and collaboration within the design team (Carrillo et al, 2000; Churchill and Thoren, 2009; CIB, 2009; Huijsmans, 2009).

An initiative which is focused on increasing integration and collaboration is described by the American Institute of Architects (AIA) as Integrated Project Delivery (IPD) (AIA, 2007; Churchill and Thoren, 2009). IPD is described as “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction” (AIA, 2007). This integration is reached through agreements and contracts between the members of the multi-disciplinary design team, as well as the use of current computer technologies and methods to define and measure project goals. The use of IPD results in a distribution of design effort more towards the start of the design phase (AIA, 2007), as shown in figure 2.2. As a result of the increased design team integration and collaboration and the increased amount of design effort during the design phase, IPD is expected to offer improved performance for the AEC design process.

Comparable to IPD, the International Council for Research and Innovation in Building and Construction (CIB) describes an alternative initiative as Integrated Design and Delivery Solutions (IDDS), which focuses on: “the use of collaborative work processes and enhanced skills, with integrated data, information, and knowledge management to minimize structural and process
inefficiencies and to enhance the value delivered during design, build and operation and across projects” (CIB, 2009). In order to reach this goal, IDDS envisions a more holistic approach which integrates work processes, technologies for collaboration and automation and experienced project teams (CIB, 2009). Similar to IPD, IDDS focuses on collaborative business structures and technological systems which aim to deliver improved integrated collaboration. In addition to this, IDDS also focuses on the development of people involved in the design process.

The development of both IPD and IDDS is closely related to the development of computer technology. At first, Computer Aided Design (CAD) was developed and applied for the production of 2D computer drawings, whereas in the 1990’s, 3D visualization or virtual modeling became available (Issa, 2003). Current initiatives in the field of computer technology are focused on Building Information Modeling (BIM), which is referred to as one of the most promising developments for the AEC industry (Eastman et al, 2008; Spekkink et al, 2009). BIM is virtual modeling of a design, which results in a multidimensional combined with all relevant data for the development of the building. Spekkink et al (2009) mention that currently, 3D visualizations are increasingly used in the AEC design process and several actors have also started to use BIM. Moreover, they argue that 3D modeling or BIM result in better quality, less costs and more added value for clients and end users. Sebastian (2009) identifies BIM as an important supporting technology for integrated design approaches. As such, BIM is claimed to be an important supporting technology for IPD and IDDS (Churchill and Thoren, 2009; AIA, 2007; CIB, 2009). Besides offering multi-dimensional visualization of the design and exchange of design data within the design team, BIM and other computer based virtual modeling and analysis tools are used to simulate and predict design performance (Flager and Haymaker, 2007). As such, BIM offers possibilities to improve the AEC design process.

Although BIM is expected to improve the AEC design process, the actual use of BIM in practice still appears to be challenging. Interoperability issues exist; in other words, data exchange between software applications from different manufacturers is difficult (Shen et al, 2009; Amor, 2009; Farinha et al, 2007). Actors from different disciplines involved in the AEC design process use discipline-specific software applications. As a result of the interoperability issues between the software applications used, data exchange within the multi-disciplinary design team is experienced to be limited or even frustrating (Issa, 2007). However, standard exchange languages such as the Industrial Foundation Classes (IFC) are developed in order to solve the interoperability issues (Shen et al, 2009). Nevertheless, Churchill and Thoren (2009) describe that interoperability issues still exist and are identified as limitations of current BIM use. Moreover, legal issues and risk allocation are limiting BIM use as well. Churchill and Thoren (2009) state that actors are reluctant towards taking responsibility for the integrity of the BIM models and that therefore disclaimers are used in an attempt to renounce responsibility. It is also claimed that 3D visualizations and BIM enable labeling of all data in the model, which makes it easier than before to show design responsibilities (Chao-Duivis, 2009, cited in Churchill and Thoren, 2009). Nevertheless, it can be concluded that issues with regard to interoperability and legal responsibility still appear to be challenging in relation to BIM use.
Besides the relation with technology-driven developments such as BIM, approaches such as IPD and IDDS are related to developments of alternative business models. For example, alternatives for the traditional Design-Bid-Build business model are developed, such as Construction Management business model and the Design-Build model (Churchill and Thoren, 2009; AIA, 2007). The Construction Management business model is focused on early involvement of the contractor and suppliers, whereas the Design-Build business models aim to reduce risk and coordination effort by creation of a single point of responsibility for both design and construction. Although new business models have been developed, the traditional Design-Bid-Build business model is still prevailing in The Netherlands (Jansen en Vrolijk, 2009). Although developments in the field of alternative business models are undertaken, use alternative business models still appears to be limited.

Other initiatives in the industry currently focus on social aspects of team collaboration as well as the development of knowledge and skills among professionals in the industry (CIB, 2009; AIA, 2007; Kunz and Fischer, 2009). For example, research is performed about collaboration within a team of professionals at physically one location, which is also referred to as co-located collaboration (Mark, 2002; Garcia et al, 2004). Mark (2002) claims that co-located environments increase productivity of teams. However, it is also stressed that such integrated and co-located work processes require different skills and knowledge of professionals as well as different roles in the design team (CIB, 2009; AIA, 2007; Mark, 2002). It is increasingly acknowledged that besides technological development, aspects such as work processes, knowledge sharing and balanced teams of skilled professionals should be taken into account to improve performance (Rekola et al, 2009; Sebastian, 2009). In other words, the focus is shifting from a solely technology oriented approach towards more organization and process oriented approaches that increasingly focus on social aspects of team collaboration.

Initiatives such as IPD and IDDS combine the various developments with regard to technology, business models, organization and process into one integrated design approach. Through this combination of technology, business models, organization and process, the approaches aim to increase integration and collaboration within design teams (AIA, 2007; CIB, 2009). Moreover, the integrated design approaches result in a distribution of design effort directed more towards the start of the design phase (Aranda-Mena, 2008; Aranda-Mena et al, 2009; AIA, 2007). As a result of the increased design team integration and collaboration and the increased amount of design effort during the design phase, integrated design approaches are expected to offer improved performance for the AEC design process.

Although integrated design approaches such as IPD and IDDS are identified as promising, the AEC industry struggles with the implementation of these approaches in practice. The literature about IPD and IDDS focuses specifically on the definition of a vision about integrated design, instead of describing the steps to take to reach this vision.

Comparable to IPD and IDDS, Virtual Design and Construction (VDC) is referred to as an integrated design approach which is focused on increasing integration in the industry (Owen, 2009; Garcia et al, 2004; Kunz and Fischer, 2009). Virtual Design and Construction aims to improve multi-disciplinary design team collaboration by using visualization tools as well as performance measuring tools at the
levels of the design, the design team and the design process (Kunz and Fischer, 2009). Whereas IPD and IDDS focus on the vision about integrated design, VDC is more focused on operational aspects to bring that vision to life. For example, VDC provides tools and suggestions which are claimed to reach design integration in the design process of AEC projects. As such, VDC is an approach which provides several steps to take in order to reach an integrated design process. However, VDC is still developing and implementation of the VDC approach has only taken place within case study pilot environments in the US, performed by the developers of VDC. Insight into the implementation of VDC in real-life projects is scarce and companies struggle with the implementation of the VDC approach in their design process. Therefore, this research specifically focuses on the implementation of Virtual Design and Construction (VDC) in large, real-life AEC projects. VDC will be described more elaborately in the following sections. First, the development of VDC is described. Secondly, the components of VDC are explained, followed by a description of the implementation phases defined in VDC theory. Finally, several VDC implementation experiences are presented.

2.2 The development of Virtual Design and Construction
The Center for Integrated Facility Engineering (CIFE), which is part of Stanford University from the United States of America, performs research into the design and construction process. Researchers at CIFE identified the fragmentation of the design process (Kunz and Fischer, 2009). They mention that the necessary alignment between organizations in the multi-disciplinary design team is difficult. For example, exchange of information and making decisions is experienced to be difficult. This difficulty results in a long process duration. Besides the long process duration, Kunz and Fischer (2009) also mention that actors involved in the design and construction process experience the process as arcane and complex. In addition to that, Kunz and Fischer describe that the design and construction process is experienced as paper based and inflexible.

In response to the fragmentation, complexity and inflexibility of the design and construction process, CIFE introduced Virtual Design and Construction (VDC) in 2001 (Kunz and Fischer, 2009). VDC is an approach which is based on “integrated, multidisciplinary, performance based virtual design and construction modeling” (Garcia et al, 2004; CIFE Stanford, 2011a). Kunz and Fischer (2009) describe that the VDC approach is integrated, because data is shared and accessible for all actors in the design team. The approach is described as multidisciplinary because actors from main disciplines such as architecture, engineering, contracting, as well as the sub-disciplines and the client are involved. The approach is performance based in the sense that the objectives for the project performance are determined in advance and performance can be predicted and measured during the process. Finally, Kunz and Fischer (2009) describe that VDC is virtual, because VDC models are computer based, which makes the models flexible, visual and interactive to use.

The VDC approach focuses on three main controllable factors which are present in every design-construction process (Kunz and Fischer, 2009; Garcia et al, 2004): Product, Organization and Process (POP). The Product (P) is the building which is being designed and build. The Organization (O) stands
for the professionals, stakeholders or organizations who are involved in the design and construction of the building. The Process \((P)\) stands for the process of the design and construction of a building. Furthermore, the VDC approach supports Integrated Concurrent Engineering (ICE) (Kunz and Fischer, 2009), which is defined by Chachere et al (2004) as “a singularly rapid combination of expert designers, advanced modeling, visualization and analysis tools; social processes and a specialized design facility; to create preliminary designs for complex systems”. ICE is also referred to as “Extreme Collaboration” (XC) (Garcia et al, 2004).

Garcia et al (2004) expect the VDC approach to improve quality and reduce rework, by combining Product, Organization and Process. They mention that a concurrent focus on Product, Organization and Process, triggers actors to think about the design activities (process) and the work force (organization) related to design and design choices (product). Kunz and Fischer (2009) describe that VDC is expected to improve project performance. Although performance is not defined, VDC literature shows that Kunz and Fischer (2009) aim to increase project quality and decrease project duration. The VDC approach consists of several components. These VDC components are described below, as well as their intended purpose.

### 2.3 Components of the VDC approach

The VDC approach consists of several components, which are shown in figure 2.3. The VDC approach uses POP visualizations and POP metrics. The POP visualizations are used to visualize the Product, Organization and Process. The POP metrics are used for the performance measurement of the Product, Organization and Process. Both POP visualizations and POP metrics are used in the process of Integrated Concurrent Engineering (ICE). These VDC components are described in more detail below.

<table>
<thead>
<tr>
<th>Integrated Concurrent Engineering (ICE)</th>
<th>Co-located collaboration in the iRoom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td>The design/building</td>
</tr>
<tr>
<td><strong>Organization</strong></td>
<td>Design team/stakeholders</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Design/construction process</td>
</tr>
<tr>
<td><strong>Visualizations</strong></td>
<td>BIM, 2D drawings, 3D drawings</td>
</tr>
<tr>
<td></td>
<td>organization charts, stakeholder diagram</td>
</tr>
<tr>
<td></td>
<td>planning charts, design task lists</td>
</tr>
<tr>
<td><strong>Metrics</strong></td>
<td>requirements with regard to the building, PoR</td>
</tr>
<tr>
<td></td>
<td>requirements with regard to the actors</td>
</tr>
<tr>
<td></td>
<td>requirements with regard to the process</td>
</tr>
</tbody>
</table>

![Figure 2.3: VDC approach and VDC components](image)
2.3.1 Virtual POP visualizations

Traditionally, the AEC industry focuses on visualizations of the product. For example, AEC practice focuses on drawings or models of the building design. Kunz and Fischer (2009) mention that the project organization and project process are not modeled, visualized and analyzed accurately and effectively. Moreover, they mention that management and communication of multidisciplinary information and processes is often performed ad hoc. Therefore, Kunz and Fischer (2009) describe that the VDC approach not only uses product visualizations, but also organization and process visualizations. As BIM use in the AEC industry is increasing, the necessity of organization and process modeling is identified more widely, as shown by the following definition of BIM (Associated General Contractors (AGC), 2006 cited in Aranda-Mena et al, 2008):

“Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users’ needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility. The process of using BIM models to improve the planning, design and construction process is increasingly being referred to as Virtual Design and Construction (VDC).” – AGC (2006) cited in Aranda-Mena (2008)

The VDC approach specifically focuses on visualizations of the Product, Organization and Process. Product visualizations are visual representations of the building design which is developed. The Organization visualization displays the design team and stakeholders involved in the development of the building design. The Process visualization shows the design process followed by the design team to develop the building design. POP visualizations are virtual, which means that these visualizations are computer based. The POP visualizations are meant to be more flexible, visual and interactive in use than their paper based counterparts (Kunz and Fischer, 2009). For example, computer based visualizations are made of components and layers and could contain a combination of all sorts of data which enables more flexible and interactive use. Also, computer based visualizations of the product can be rotated and components and layers can be switched on and off to enhance focus and insight into a specific part of the design. Kunz and Fischer (2009) describe that the visual display make the content of a POP visualization more accessible than traditional static paper descriptions. The visualizations of the Product, Organization and Process are described in more detail below.

Product visualizations

The Product visualizations are a representation of the design of the product or, more specifically, the building. These visualizations contain information about the layout of all of the components of the design, such as walls or floors. Depending on the purpose of the visualization and on the project phase, the level of detail of the visualization is expected to differ. Instead of 2D paper drawings, the product visualizations exist of digital, interactive CAD models, which consist preferably of three or more dimensions (Kunz and Fischer, 2009). Kunz and Fischer (2009) claim that multi-dimensional
models are more understandable than 2D drawings. They explain that the models are supposed to be related, meaning that changing or highlighting parts of the design in one model will lead to rapid or instant changing or highlighting of the other related models. Kunz and Fischer (2009) expect that the usage of interactive multi-dimensional and interrelated models leads to decreasing time for explanations and decision making, as well as a decreasing amount of design and construction rework. Also, they mention that the visual aspect of models support multi-cultural teams, because the team members have the same visual information and therefore language barriers are overcome.

Organization and process visualizations

The organization visualizations are the visual representations of the organization involved in the design and construction of the building (Kunz and Fischer, 2009). As such, this organization consists of actors such as the architect, the engineers, the advisors, the contractor. Also, stakeholders and decision makers such as the client are part of the organization visualization. The organization is visualized using an organization chart, which shows a network of the actors and stakeholders involved in the project process (Kunz et al, 1998), as well as the reporting paths (Kunz and Fischer, 2009).

The process visualizations represent the design and construction process which the organization follows to develop the building (Kunz and Fischer, 2009). The process consists of tasks, activities or actions which have to be undertaken by the organization. The process is visualized in a process diagram (or activity diagram), ideally in the shape of a network diagram, showing the activities or design tasks, task interdependencies and deadlines (Kunz et al, 1998).

Kunz and Fischer (2009) describe that the “Virtual Design Team” (VDT) method is used to visualize and manage the organization and process. The idea behind the VDT method is that organizations and processes are managed by building and analyzing visualizations and computational models of the organization and process (Kunz et al 1998). This means that organization and process are modeled and designed in advance, and then analysis is performed to determine the organization and process performance. The VDT method combines the organization chart and the process diagram into one VDT model, showing multiple types of relationships (Kunz et al, 1998), as shown in figure 2.4. First, relationships between actors show lines of communication between actors. Second, relationships between actors and tasks show responsibility of actors for specific tasks. Finally, relationships between tasks show the interdependency among tasks.

![Figure 2.4: Organization and process visualization, source Kunz et al (1998)](image-url)
Kunz et al (1998) describe an organization as an “information-processing and communication system, structured to achieve a specific set of tasks, and composed of limited teams that process information”. Therefore, modeling of organization and process with the VDT method not only focuses on task interdependency, task size and task duration. In addition, the VDT method also focuses on factors such as task complexity, task uncertainty, actor skill and actor experience (Kunz et al, 1998). A value “high”, “medium” or “low” is allocated to these factors, which influences the total outcome of the VDT simulation. Whereas the conventional Critical Path Method mainly focuses on task sequence, the VDT method also shows the probability of task failure and the required communication intensity, which is claimed to result in a more explicit representation of the coordination among actors involved in the design and construction process (Kunz et al, 1998).

Purpose of the VDT method is to get insight in the organization and process through modeling and simulation. Kunz et al (1998) mention that when tasks and actors are identified, the VDT simulation predicts the presence of bottlenecks in both organization and process. They describe that this insight can be used to take action to decrease the bottlenecks, by decentralizing decision making, changing the design team composition or design team structure or changing communication tools. Because the VDT simulation is computer-based, changes in the organization or process can be analyzed repeatedly, showing the consequences of changes on the efficiency and effectiveness of the organization and the process (Kunz et al, 1998). Although the VDT method is described in VDC theory (Kunz and Fischer, 2009), it is not described how this method should be applied in VDC projects.

2.3.2 POP metrics

Besides the POP visualizations, the VDC approach uses POP metrics. These POP metrics can be defined as explicit requirements or objectives, which are used to predict or measure performance of the Product, Organization and Process (Kunz and Fischer, 2009). The POP metrics can be used to make an assessment of the performance of the Product, Organization and Process at every moment during the design and construction process. The actors involved in the design and construction process can use this assessment to manage and steer the process along the way.

The POP metrics are placed in a POP model. An example of such a POP model is shown in figure 2.5. The POP model is based on the aspects form, function and behavior, which are described by Clayton et al (1996). Clayton et al (1996) described form as the geometry of the design, containing physical components such as walls or floors. Function is defined as all requirements, needs, intents and design objectives. Behavior is defined as the expected performance of the design, e.g. the extent to which the form satisfies or fulfills the intended function. Whereas Clayton et al (1996) focused on issues of design, related to space, cost, scheduling or energy, Kunz and Fischer (2009) used form, function and behavior to describe the requirements and performance of the Product, Organization and Process in the POP model. They added several other aspects and combined it in the POP model, resulting in a POP model which describes five main aspects for the Product, Organization and Process: (1) function, (2) form or scope, (3) behaviors, (4) weighting factors and (5) threshold values.
The first aspect, function, describes the functional requirements or objectives for the Product, Organization and Process (Kunz and Fischer, 2009). These requirements or objectives can come from the Program of Requirements, from regulations set by regulatory stakeholders or from agreements made within the design team. In the POP model, function is divided into a “measurable objective” and a “demanded objective value”. The first is the requirement or objective itself; the latter is a measurable, in many cases numeric, value demanded for the objective. An example of a measurable objective for the Product is the size of meeting rooms in an office, or the total size of living space in a dwelling. In both examples, the demanded objective value could be an amount of square meters. An example of a measurable objective for the Organization is the requirement of the involvement of a structural engineer throughout the complete design process. In that case, the demanded objective value can be a percentage, e.g. hundred percent involvement. An example of a measurable objective for the Process can be the presence of decision making moments. The demanded objective value could then be an amount of decision making moments.

The form or scope is the way in which the functional objectives for the Product, Organization and Process have been given shape (Kunz and Fischer, 2009). In case of the Product, form can be the type of structural components to provide sufficient load bearing capacity. An example of Organization form is a specific line of communication between actors or hierarchical or contractual organization of the design team. An example of Process form is the construction plan (Kunz and Fischer, 2009).

Behavior indicates the predicted and measured degree in which the form or scope fulfills the functional objectives for the Product, Organization and Process (Kunz and Fischer, 2009). The “weighting factors” indicate the importance of the functional objectives in comparison to each other. “Qualitative threshold values” are defined by the actors involved in the project. These values are used to determine the assessed behavior of the functional objectives. The combination of the weight factor value and the assessed behavior provides a total weighted assessment for every functional objective. The values in the column for weighted assessment can be compared with the weighted value to see whether or not the functional objective scored above target. The sum of the values for the weighted assessment shows the project evaluated goodness, which is an indicator that shows the performance of the Product, Organization and Process. The assessment of the performance can take place every day, week, month or major milestone, depending on what is appropriate (Kunz and Fischer, 2009).

<table>
<thead>
<tr>
<th>Function</th>
<th>Form/Scope</th>
<th>Behaviour</th>
<th>Weighting factors</th>
<th>Qualitative threshold values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Predicted</td>
<td>Assessed</td>
</tr>
<tr>
<td>Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking places</td>
<td>200</td>
<td>7p</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Costs per parking place</td>
<td>20000</td>
<td>7p</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Organization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actors attending meetings (%)</td>
<td>95</td>
<td>7p</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Actor backing (days)</td>
<td>&lt;3</td>
<td>7p</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conformance with schedule (%)</td>
<td>85</td>
<td>7p</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Maximum schedule delay (weeks)</td>
<td>0</td>
<td>7p</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Project evaluated goodness</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure Z.5: POP model showing all POP metrics, source: Kunz and Fischer (2009), edited
The POP metrics and the POP model can be composed at different levels of detail. Kunz and Fischer (2009) describe the use of level-A, -B, -C and also level-D POP models. Whereas level-A POP models describe the Product, Organization and Process as one element, the lower level POP models are more detailed and describe a larger amount of measurable objectives for the Product, Organization and Process. In example, a level-A POP model describes the building, design team and design or construction process, whereas a level-C POP model describes the structural design, structural design group or structural design tasks. The breakdown of the POP model into larger levels of detail can be done with project cost, design or construction effort or project development duration in mind (Kunz and Fischer, 2009). Kunz and Fischer (2009) propose to breakdown POP models with the power of ten, meaning that the level-B POP model contains POP elements that influence the project cost, design and construction effort or project development duration with about 10% and the level-C POP model contains POP elements that each have influence of about 1%. The different levels of detail enable the design team to use different focus.

Kunz and Fischer (2009) mention that a good POP model contains POP elements which are mutually consistent in relation to each other, which are mutually consistent in detail and which are representing the most important aspects of the project. Furthermore, Kunz and Fischer (2009) explain that the value of the POP model is largest during early phases of design development, because most influence on the project is still possible.

2.3.3 Integrated Concurrent Engineering (ICE) in iRoom

In the previous sections, the POP visualizations and POP metrics were described. These components of the VDC approach can be used in combination with Integrated Concurrent Engineering (ICE) (Kunz and Fischer, 2009).

ICE is not specifically part of VDC; ICE is used throughout different industries. In their study about the usage of ICE in space industry, Chachere et al (2004) explain that ICE makes use of: “a singularly rapid combination of expert designers, advanced modeling, visualization and analysis tools; social processes and a specialized design facility; to create preliminary designs for complex systems”. Others, such as Garcia et al (2004), focused on the use of VDC in combination with “Extreme Collaboration” (XC), which is a comparable project development method established by NASA. They explain that XC consists of co-location and use of performance models and shared visualizations of information.

Both Chachere et al (2004) and Garcia et al (2004) describe the development of a complex design by co-location of professionals. Co-location means that professionals from different disciplinary backgrounds are collaborating at physically the same location. As far as AEC projects are concerned, these professionals often come from different companies or organizations. The co-located collaboration enables that the professionals can discuss, explain, analyze and work on the project in each other’s presence, instead of working on the project individually at their own office.

Besides co-location, Chachere et al (2004) and Garcia et al (2004) describe that several tools are applied during the process, such as modeling and visualizations tools. These tools are meant to support the concurrent collaboration between the co-located design team. For example, models and
visualizations show the current status of the design and help the professionals in the design team to understand or analyze design options.

In addition to co-location and tools, Chachere et al (2004) mention that social processes and specialized facilities are also part of ICE. Mark (2002) studied XC used by NASA design teams and provided specific insight into the social processes and specialized facilities. Mark (2002) described that XC takes place in an electronic and social environment, comparable to the iRoom, which is described as “warroom”. Mark (2002) mentions that this room has the purpose of maximizing communication and information flow. The “warroom” is described as a room with technologies such central displays and computers with databases, visualization programs and networks. A design team works in the “warroom” to develop designs for space missions. Mark (2002) described that design team members work individually, in small groups or with the entire team interchangeably. A combination of social and electronic networks is used to support communication and information exchange (Mark, 2002). A more extended version of the “warroom” is used by the European Space Agency (ESA). ESA started with the development of a Concurrent Design Facility (CDF) in 1998 (ESA, 2011). The CDF is composed of a main design room and several supporting design rooms, which all contain multiple screens to visualize information.

Kunz and Fischer (2009) combined visions about the co-located ICE method, tools and the “warroom” with the VDC components. Specifically in relation to VDC, they describe that the purpose of ICE is to increase focus of the design team members. Therefore, they describe that the need to clarify goals, methods and vocabulary is decreased. Because actors are physically in one room, the goals, methods and vocabulary are more explicit and understandable. Besides that, the waiting time for responses to questions and request for information is reduced (Kunz and Fischer, 2009).

The POP visualizations and POP metrics from the VDC approach can be used as tools which support the co-located ICE process (Garcia et al, 2004; Kunz and Fischer, 2009). As such, the POP visualizations are meant to increase insight and POP metrics can be used to steer on project performance. As a continuation of the “warroom” idea, Kunz and Fischer (2009) introduced the term “iRoom”, which is defined as an interactive meeting room in which the co-located ICE process is supported by multiple interactive presentation touchscreens, also referred to as ‘SmartBoards’. Also, computers with necessary software and networks are present in the meeting room.

Figure 2.6 shows the iRoom at CIFE, Stanford University. SmartBoards are positioned at one side of the room. The actors are positioned at the tables opposite to the SmartBoards. The SmartBoards are connected to computers and can be controlled by mouse and keyboard, or by using the touch functionality of the screens with hands or using one of the touch screen pens. As shown in figure 2.6, actors can work on their own laptop. The computers in the iRoom are connected to a network and a shared database, which should supports information flow. The large screens are used for central presentation of different types of information. For example, meeting agenda, design model, textual information and planning could be visualized simultaneously. Kunz and Fischer (2009) claim that the visualization technologies used in the iRoom allow actors to explain and interpret information more

Traditionally, project organizations are characterized by vertical hierarchical organization structures and managers involved at different levels of the organization hierarchy. In the ideal ICE process, the organization structure is flat, with minimal organization boundaries and manager involvement (Kunz and Fischer, 2009). Instead of managers, a VDC facilitator manages the ICE process in the iRoom. This facilitator should facilitate the design team actors and ensure these actors can always proceed with their design task (Chachere et al, 2004). As such, the facilitator focuses on the social processes taking place in the iRoom as well as the flow of digital information within the design team (Mark, 2002). During an ICE process, multiple processes may take place simultaneously. The facilitator needs to keep an overview of all of these processes. Therefore, the facilitator should have multi-tasking capabilities as well as social skills and technical knowledge.

2.4 VDC maturity model; implementation phases of VDC
Research conducted about VDC as well as its use in practice, showed how users implement the VDC approach. Based on the insight into the ways of VDC implementation applied by users, a model with implementation phases was developed, which is called the “VDC maturity model” (Kunz and Fischer, 2009). This maturity model is composed of three phases which can be distinguished when looking at VDC implementation. The phases of the VDC maturity model are visualized in figure 2.7.
The first phase described by Kunz and Fischer (2009) is the phase of **visualization and metrics**. During this phase, the design team members create visualizations, such as 3D models of the product, organization models of the project organization and process models for the project process. Also, the design team members use metrics to predict and measure the project performance with regard to product, organization and process. The phase of **visualization and metrics** does not yet require integration of visualizations and models among the multi-disciplinary design team actors. Such integration is part of the second phase described by Kunz and Fischer (2009), which is therefore called the phase of **integration**. In this phase, project data is exchanged and integrated by using automated (computer-based) exchange methods that enable exchange between different software applications. For example, the project data from the architectural model and the structural design model are exchanged and integrated. Such computer-based data exchange and integration between different software applications requires a sufficient degree of interoperability between different software applications, meaning that the software applications are capable of “understanding” each other’s file format. Interoperability is tried to be reached through the development of IFC (Industrial Foundation Classes), which is a standardized exchange language for software applications. However, IFC is currently not widely used (Kunz and Fischer, 2009). Although more difficult to reach, the integration phase is expected to add value through the reduction of modeling effort and time (Kunz and Fischer, 2009).

The third and final phase described by Kunz and Fischer (2009) is the phase of **automation**. This phase is about further automation of what they call “routine” design tasks, which are design tasks which do not require much analysis of the design team actors and can therefore be automated. That way, the design team actors are expected to save time and effort. Besides automation of these routine design tasks, the phase of automation is about prefabrication of the building. Kunz and Fischer (2009) expect that automation and a shift from current design-bid-build processes towards
design-prefabricate-assemble processes will lead to increased design efficiency and effectiveness as well as to a decrease in construction duration.

2.5 Experiences with VDC implementation

The VDC approach is currently developing and first experiences with the implementation of VDC in projects in practice are available. This section provides a brief overview of two case studies about the use of VDC in projects in practice. These case studies show to what extent the VDC approach was used. Also, the case studies provide insight into the experiences.

2.5.1 Template-Hospital Charrette exercise

Type of project

As part of the end of a one-week workshop at CIFE in 2003, a six-hour group exercise was held, in which use was made of the VDC approach (Garcia et al, 2004). The exercise was the development of a hospital design for a large healthcare organization which wants to construct approximately twenty hospitals at different locations. This large healthcare organization is looking for a design template for all of these hospitals. The exercise was worked out by a group of six graduate students, working in the roles of VDC project coordinator, owner’s representative, architect, project manager (Garcia et al, 2004). The exercise was observed by an audience composed of project managers from multiple different companies. At the end, the audience was asked to evaluate the exercise.

VDC usage during the project

The exercise was carried out during an Extreme Collaboration (XC) session, which meant that the group worked in a collocated iRoom environment with SmartBoards (Garcia et al, 2004). Models were made which focused on the product, organization and process. Garcia et al (2004) describe that 3D drawings were used, PowerPoint slides were used to document the architectural program, and a POP model to check design performance.

Project experiences and results

Garcia et al (2004) measured the frequency of occurrence of specific events during the XC session compared to a usual engineering meeting. Six types of events were observed in both types of meetings: (1) describe events, (2) explain and evaluate events, (3) predict events, (4) alternative events, (5) decide events and (6) negotiate events. Compared to a usual engineering meeting, it appeared that during the XC session, more time was used for decision making as well as explanation and evaluation. During the XC session, less time was spent on negotiation and describing. The occurrence of predict events were the same in both types of meetings. In general, Garcia et al (2004) claim that the usage of VDC visualizations and metrics combined with XC leads to faster and more effective early design.

The case study showed that it appeared to be rather difficult to implement the VDC approach to full extent. Garcia et al (2004) mention that the POP models appeared to stay on a high level of abstraction, e.g. 10-15 general objects were used to represent the Product, Organization and Process.
They suggest to use a simple POP ontology and expand from that point. Although some project managers from the audience were interested in trying out the VDC approach, most of the audience believed the VDC approach was not mature enough to result in radical change.

2.5.2 Case study: Camino Medical Group

Type of project
Khanzode et al (2008) performed a case study about the Camino Medical Group project. This project was about the design for a Medical Office Building in California, which was developed between 2005 and 2007. During this project, several aspects of VDC were used for the coordination of design for the Mechanical, Electrical and Plumbing (MEP) systems. The project team existed of the owner, architect, general contractor, MEP engineers and several subcontractors.

VDC usage during the project
With regard to VDC, the project specifically focused on the use of 3D/4D product visualizations (Khanzode et al, 2008). These visualizations existed of virtual models which were used for the coordination of the MEP design work. More specifically, the models were used for the detection of clashes between different MEP systems. In addition to the use of the product visualizations, the project team also worked in the “Big Room”, which is an interactive meeting room comparable to the iRoom. Besides the product visualization and the collaboration in the Big Room, the case study article does not describe the use of other VDC components, which suggests that organization visualizations, process visualizations and POP metrics were not applied in the project.

Project experiences and results
Khanzode et al (2008) described several experiences which were found during the case study. First, the design team experienced that the absence of the fire safety advisor during meetings in the Big Room resulted in some problems between MEP systems and fire protection systems. The design team actors thought that most of these issues could have been prevented if the fire safety advisor would have been present during the meetings. Second, Khanzode et al (2008) describe that the design team actors experienced that the actors had to collaborate in the Big Room for almost two days per week in order to create a smooth process. Third, the 3D product model appeared not to contain sufficient information to prevent clashes at a larger level of detail.
Khanzode et al (2008) mention that the use of VDC product visualization models resulted in a decreasing amount of Requests For Information (RFIs). It is also claimed that time and budget savings were reached through the use of VDC. Khanzode et al (2008) mention that subcontractors had few rework and finished their work on schedule or even ahead of schedule. Moreover, the product model is said to be used for facility management as well.
2.5.3 Feedback from VDC certificate course program attendees

CIFE provides a VDC certificate course program for employees of companies in practice. By following this course program, employees can be awarded with a VDC certificate. As a part of the VDC certificate course program, course attendees write monthly reports of their VDC implementation status and experiences from projects at their company. Every course attendee is required to submit at least six status reports. These monthly feedback reports provide insight into the overall status of VDC implementation, as well as the problems or difficulties faced by the companies using VDC. The monthly feedback reports of three different course groups have been analyzed. The choice was made to analyze the latest report submitted by the course group attendees, because these reports show the extent to which VDC was implemented after a tryout period of several months.

The monthly feedback reports show that different combinations of VDC components are used by the course attendees. Whereas some attendees especially focused on the use of product visualizations and BIM, others also used POP metrics in their project. Also, the monthly feedback reports show slight differences in the way the VDC components were used. For example, some attendees used a power-influence diagram to visualize the stakeholders in their project, while others used a different type of diagram which seems to describe the attitude of stakeholders towards VDC.

The monthly feedback reports suggest that product visualizations and POP metrics are used most. Especially the POP metrics are used by the attendees. The metrics are developed and elaborated throughout the process. Most common measurable objectives found in the POP metrics are participation of actors, schedule conformance, actor backlog, the amount of Requests For Information (RFIs) and the latency in response to RFIs.

Because no background information is available about the projects described in the monthly reports, the conclusion which can be drawn from these documents is limited. Nevertheless, the monthly reports show a certain emphasis of course attendees on the implementation of product visualizations and POP metrics. Moreover, the monthly feedback reports show that the combination of VDC components differs throughout projects.

2.6 Concluding remarks

This chapter described the theoretical backgrounds for this research. The literature study provided an overview of current challenges in the AEC industry and the need to increase performance in AEC projects. Several initiatives have been identified, which are undertaken to improve the performance of the AEC industry through integrated collaboration. Recently developed initiatives, such as IPD and IDDS, seem to focus on describing a rather visionary goal of improving the industry’s performance by means of integrated collaboration. In order to reach integrated collaboration, IPD and IDDS are combining various developments in the AEC industry. However, IPD and IDDS are mainly describing visions and offer limited suggestions to translate those visions into practice.

Comparable to IPD and IDDS, VDC claims to increase performance through integrated collaboration by combining different developments in the AEC industry. However, the literature study showed that VDC has a different emphasis than IPD and IDDS. Whereas IPD and IDDS focus on the definition of visionary goals, VDC contains a stronger emphasis on practical tools and methods by which those
visions are claimed to be translated from theory into practice. In other words, VDC and the VDC components can be seen as a first step to bring to life the visions described in IPD and IDDS literature.

Although VDC is claimed to offer increased performance through integrated collaboration, the actual implementation of VDC in AEC practice remains limited. Moreover, the literature study identified that examples of VDC implementation are currently limited to pilot environments and case study research in the US. This research aims to provide insight into the possibilities and limitations of VDC implementation in large AEC projects through case study research. Figure 2.8 shows the framework used for the case study research. The framework provides an overview of the VDC components and the focus of the case studies.

**POP VISUALIZATIONS**

**Product visualizations**

**Purpose:**
Support communication, increase insight, accessibility, flexibility, interactivity, interrelation.

**Necessary implementation factors:**
- Digital, interactive CAD models
- Multi-dimensional
- Interrelated models
- Shared drawing methodology

**Organization visualizations**

**Purpose:**
Increase explicit insight into coordination among actors (e.g. required communication intensity, bottlenecks in organization capacity).

**Necessary implementation factors:**
- Actors and stakeholders
- Reporting paths
- Decision authorities
- Modeling factors (e.g. actor skill/experience)

**Process visualizations**

**Purpose:**
Increase explicit insight into process and design tasks (e.g. probability of task failure, bottlenecks in process planning).

**Necessary implementation factors:**
- Task and activities
- Task responsibilities
- Task deadlines
- Interdependency
- Modeling factors (e.g. task complexity, task uncertainty)

**POP METRICS**

**Purpose:**
Assessment and management of POP performance.

**Necessary implementation factors:**
- Function (measurable objectives, objective values)
- Form/scope
- Behavior
- Weighting factors
- Threshold values
- Different levels of detail

**ICE IN IROOM**

**Purpose:**
Increase focus, assure clear and unambiguous goals, methods, vocabulary; reduction of waiting time and requests of information.

**Necessary implementation factors:**
- Co-located collaboration
- Use of interactive meeting environment
- Application of VDC visualizations and metrics
- VDC facilitator support

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**Figure 2.8: Analytical framework**
3. Case study VDC: Parking Garage Amersfoort

This chapter describes the VDC case study performed for this research. This VDC case study is a Parking Garage project in Amersfoort. This project is a pilot during which the VDC approach was applied during the design process. This chapter describes the VDC design process of the case study project.

The aim of the case study is to identify the use and implementation of VDC during the design process of the project. The use of VDC in Dutch practice is rather new and VDC is not yet applied in many projects. The case study provides insight into the current status of VDC application in practice. As such, the case study presents what components of VDC were applied and what problems were experienced. A description is given about the project in general, the actors involved in the project and the VDC elements used throughout the design process.

3.1 Case study introduction: Parking Garage Amersfoort

3.1.1 Reasons for the initiation of the project

The main office of DHV is positioned at the south of Amersfoort, near the highway A28. Although public transport to the train station of Amersfoort is available, a significant amount of employees and visitors are travelling to the main office by car. This results in a need for more than 500 parking places in close vicinity of the office building. Currently, parking facilities near the main office building are offered by a multilayer underground parking garage below the office building and two parking areas next to the office building. One of the parking areas is positioned on land which is rented by DHV from a third party. Because the rental period of this land is expiring in June 2011 and DHV expects the parking demand to stay at least equal, parking capacity has to be created elsewhere. No land seems to be available in the direct surroundings, which means that the parking capacity has to be developed at the remaining terrain around the office building. Being one of the four Shared Services Centers (SSC) at DHV, SSC Facilities is responsible for facilities such as parking. Therefore, SSC Facilities acted as delegated project manager for DHV. As such, SSC Facilities performed an initial analysis about the parking problem. Based on this analysis, SSC Facilities decided that a possible and feasible solution for the parking problem could be the development of a parking garage at the parking area which is part of the DHV terrain around the main office. A project team was formed during the summer of 2009, to investigate the possibilities to solve the parking problem by developing a multilayer parking garage.
3.1.2 Development of the Parking Garage project

The development process of the VDC project is partially shown in figure 3.1. At July 2009, SSC Facilities send a memo to an architect from within DHV, which contained a description of the parking problem, the demands and requirements and the assignment for the architect. Based on the memo, the architect sketched several design alternatives. Meanwhile, a design team with actors from different disciplines was composed to realize the project. Simultaneously, DHV started with the development of VDC implementation within the company. In consultation with the design team, SSC Facilities decided to use the Parking Garage project as a pilot environment for the implementation of VDC. During the preliminary design phase, the design team used the VDC approach for further development of the design variants which were made by the architect. Eventually, one design variant for the parking garage was chosen and worked out in more detail. However, as a result of the economic crisis, the project progressed slowly and even came to a standstill. Decision making time was needed to determine whether or not the investment for the parking garage would take place. Before the start of this case study research, the preliminary design (PD) for the parking garage was finished. During the case study, the tender phase was held to select a contractor for the engineering and construction of the parking garage. Currently, it has to be decided whether or not the parking garage will be build.

![Figure 3.1: Project timeline, project parking garage Amersfoort](image)

3.1.3 Scope of the case study

The case study specifically focuses on the preliminary design process of the project Parking Garage in Amersfoort, because this was the period during which the VDC approach was used most. Between the end of August 2009 and December 2009, the VDC approach was applied during the design process and five ICE meetings were held. During this VDC design process, several elements of VDC were applied for the development of the preliminary design, which makes this period valuable for the case study research. The preliminary design process for project Parking Garage is partially visualized in the timeline diagram in appendix II. This diagram displays the period from August 2009 until December 2009 and shows the design team meetings, actor involvement, email interaction and use of VDC components.
3.2 Preliminary design phase

The VDC case study focuses on the use of VDC during the preliminary design process of the project Parking Garage Amersfoort. This section describes the preliminary design process in general. Also, the actors involved in the preliminary design process are introduced. Finally, this section describes the intended use of VDC as planned prior to the start of the pilot project.

3.2.1 Preliminary design process

Before the design team was involved in the preliminary design process, the project management from SSC Facilities contacted a project leader structural engineering from DHV Buildings with experience about parking garage projects. Subsequently, the project management prepared a memo which contained the assignment for the architect as well as the requirements for the parking garage design. The memo was send to an architect from within DHV, who sketched multiple possible design variants for the parking garage, based on different types of routing concepts. The preliminary design phase started a little while later in August 2009, when the design team, composed of the architect, the project leader structural engineering, a structural engineer (VDC facilitator), traffic engineer, cost advisor and a legal advisor, held a first design team meeting. During this first meeting, the project leader structural engineering proposed to use the VDC approach for the project. Subsequently, the project leader structural engineering made a kick-off document, in which the proposed use of VDC during the project was described. From that moment, the design team worked out the design variants using the VDC approach during multiple design team meetings. After some design team meetings, the design team collectively made an assessment to determine the performance of the design variants. The assessment resulted in the selection of a preferred design variant. The assessment and preferred design variant were presented to the board of DHV. During this presentation, the decision was made that the design team should continue working out the preferred design variant. However, the design process delayed as a result of the economic crisis. In the end, the preliminary design was finished and the project was tendered to select a contractor for the engineering and construction of the parking garage. Currently, the rental period of the land is prolonged and the project is on hold.

3.2.2 Actors involved in the preliminary design phase

The project for the parking garage was developed by actors coming from different units from within DHV: the project management from SSC Facilities, the architect, structural engineers and advisor sustainability from DHV Buildings, a traffic engineer from DHV Mobility, a cost expert and a fire safety advisor from DHV Real Estate, and a legal advisor from DHV Urban and Regional Development. Although the actors work for the same company, they are stationed at four different office locations in Amersfoort, The Hague, Eindhoven and Zaandam. Actors had no working experience with each other from previous projects.

The organization chart in figure 3.2 displays the different actors involved in the VDC design process. The actors displayed in a gray rectangle were regularly participating in VDC design team meetings. Actors such as the legal advisor, specialist in sustainability and the fire safety advisor were involved in the project but did not participate in the VDC design team meetings. Some actors had a double role
in the project. For example, the project leader structural engineering was the initiator of VDC use in the project, whereas the structural engineer had the role of VDC facilitator. Both the VDC initiator and the VDC facilitator were involved in the management and organization with regard to the VDC components. All divisions and actors involved in the design process are described below, as well as their role, involvement and tasks during the design process. The timeline diagram in appendix II shows the involvement of the actors throughout a part of the design process.

**Project management: SSC Facilities**

SSC Facilities is responsible for the housing and facility services for all Dutch offices. As such, SSC Facilities is also responsible for the parking facilities at the main office in Amersfoort. For the development of the parking garage at Amersfoort, SSC Facilities is acting as delegated project manager on behalf of the board of DHV B.V., which takes the final decision about the necessary investment for the development of the parking garage.

Two employees from SSC Facilities were involved in the project; the director of SSC Facilities and the projects director of SSC Facilities, who are both working at the main office in Amersfoort. Although both directors were involved in the VDC design process through email and meetings, the projects director was acting as the project manager for this project and was the main contact person of SSC Facilities for the other actors involved in the project. The projects director had the task to manage the project of the parking garage, which means he had to approach the other actors and form a team, keep in contact with the board and provide the actors with project information, such as the project demands. The projects director was the chairman of the design team meetings. As such, the projects director attended all meetings which were held. The projects director of SSC Facilities remained in contact with the other actors by email and telephone. The director of SSC Facilities had contact with other actors less often and was sometimes present at design team meetings.
**Architects: DHV Architects**

The architectural design for the project was made by DHV Architects, which is part of the unit DHV Buildings and is positioned at the office of Eindhoven. The architect of the project was an important actor in the project. The architect was involved at an early stage of the project and made some first conceptual designs before the VDC design process started. During the VDC design process, the architect worked out several alternatives for the functional design of the parking garage and delivered floor plans and cross sections. The architect also developed multiple façade designs with different aesthetic appearances. Throughout the design process, the architect was assisted by multiple draftsmen from DHV Architects, who worked out drawings and images of the design. The architect was the only employee from DHV architects who attended the VDC design team meetings. Although the architect interacted with other actors by telephone, most interaction by email was performed by the draftsmen. The draftsmen communicated with the other actors about updated drawings and files, as well as design issues. The architect was also involved in the presentation of the parking garage design to the municipality.

**Structural engineers: DHV Structural engineering**

The structural engineering task was performed by two employees from the department of Structural Engineering, which is part of the unit DHV Buildings. Both employees, a project leader and a structural engineer, were positioned at the office in The Hague. The tasks of the employees of structural engineering were twofold. First, the project leader and the structural engineer were involved in the development of the structural design for the parking garage. They were responsible for making drawings and calculations of the structural design. During the process, a 3D model was made, which represented the structural design. The involvement of both a project leader structural engineering and a structural engineer seems to imply that both employees had different tasks. However, the division of the tasks between the two employees was not that strict. During the process, both employees from the structural engineering department were assisted by draftsmen from the department.

The second task of the project leader and the structural engineer was the task of respectively VDC initiator and VDC facilitator. The project leader was the one who proposed to use the VDC approach at the start of the design process. He prepared a kick-off document, presented the VDC approach to the design team, explained the components of the approach and proposed components which could be used during the design process. The structural engineer had the role of VDC facilitator, which meant that he had to prepare and guide the design team meetings and manage the use of the VDC components. Also, he made reservations for the meeting rooms, ensured proper functioning of the technology and the software and composed the minutes of the meetings.

The project leader was a regular attendee of the design team meetings from the beginning. The structural engineer got involved in the second design team meeting and attended all of the design team meetings from that moment on. In between the meetings, both actors interacted with other actors in the design team by email and telephone. Being the VDC facilitator, the structural engineer had much contact with other actors to organize the VDC design process. Moreover, the structural
engineer and project leader of structural engineering frequently had contact about the implementation of the VDC approach in the design process of the project.

Traffic engineer: DHV Mobility
Since the project was about the development of a parking garage, traffic engineering was an important aspect during the design process. Therefore, a traffic engineer was involved during the design process. The traffic engineer worked at the unit DHV Mobility and was stationed at the main office in Amersfoort.

The traffic engineer was involved in the project to advise about the traffic flows within the parking garage as well as the traffic flows in the surroundings of the parking garage. He analyzed the traffic flows throughout the terrain at the main office and proposed multiple alternatives for the road design. Also, he analyzed the traffic flows in the design variants for the parking garage.

The traffic engineer was a regular participant in the design team meetings. The traffic engineer worked out most drawings and documents by himself and interacted with other design team actors by email and telephone.

Cost advisor: DHV Real Estate
The cost advisor involved in the project comes from the unit DHV Real Estate and was stationed at the main office in Amersfoort.

The cost advisor provided advice about the costs of the design, by determining the investment costs of the different design variants. Also, the cost expert was involved in the determination of the Total Cost of Ownership (TCO), which provided an overview of the financial feasibility of the design variants when maintenance and operating costs are taken into account as well. The information about the costs was used for choosing one of the design alternatives.

The cost expert was involved from the third design team meeting onwards. Between the meetings, the cost expert interacted by email to send updates about the cost estimates made. Moreover, he was consulted by telephone by other design team actors for information about costs of design choices.

Other DHV actors
Besides the actors described so far, several other actors from DHV were involved in the project. Instead of being involved during design team meetings, these actors were involved for shorter periods of time and provided advice about specific fields of expertise.

First, a legal advisor from DHV Urban and Regional Development in Amersfoort provided advice about the legal issues and necessary permits. As such, the consultant had frequent contact with different departments of the municipal government. Although not present during the design team meetings, this consultant was involved throughout the total VDC design process. He received copies of the minutes and was frequently contacted by email. Most interaction took place with the projects director from SSC Facilities.

Second, two specialists in sustainability from DHV Buildings were involved in the project for a short time. One of the specialists works at the office in Eindhoven and functioned as project leader for the
project. The other specialist worked at The Hague and was responsible for the production of an advisory report about the degree of sustainability of every design variant. This advisory report was used in the assessment of the design variants at a later stage in the design process. Both specialists were not involved in the design team meetings, however, contact with other actors took place by telephone and email.

Third, a fire safety advisor from the unit DHV Real Estate in Zaandam was involved in the project. This advisor provided advice about the fire safety regulations for the design for the parking garage. Although he did not attend the design team meetings, interaction between the fire safety advisor and the other design team actors took place by email for a short period of time.

Fourth, an advisor about geotechnics of DHV Land and Water in The Hague was involved in the project for advice about the soil conditions and the load bearing capacity of the soil in particular. The advisor was not participating in design team meetings, however meetings with the structural engineer took place, as well as interaction by telephone and email.

Finally, the board of DHV was involved throughout the total development process of the parking garage. The board members did not attend any of the design team meetings, neither did they have any other form of direct interaction with the design team actors. Mainly, the board was informed by the director or projects director of SSC Facilities through meetings, emails and telephone calls. After the design variants were made, the directors from SSC Facilities held a presentation for the board.

**Other external (non-DHV) actors**

The project for the parking garage at the main office of DHV was mainly developed by actors from within DHV. However, some external actors were involved as well. External actors are all stakeholders in the project from outside DHV, who were indirectly involved in the design. The municipality is the most important external actor because multiple departments had the possibility to influence the project. For example, the planning authority, fire department, building supervision and archeology department were able to influence the design process of the project. However, these municipal departments were not involved in the VDC design process directly; the consultant for legal issues and permits functioned as a main point of contact between the design team and the departments of the municipality of Amersfoort and other governmental organizations.

### 3.2.3 Intended use of the VDC approach during the preliminary design phase

The use of the VDC approach at DHV is new and the implementation is rather experimental, therefore DHV decided to use the Parking Garage project as a pilot project for VDC implementation. This project was chosen, because DHV is the client of the project and most of the other actors involved in the development of the parking garage are from within DHV as well. In other words, the project provided a tryout environment which was useful for first experiments about VDC implementation. The goal was to experiment and to analyze the benefits, problems and difficulties of the VDC approach. These experiences and insights can be used to improve the implementation of the VDC approach and prepare the use of VDC in future projects with external (non-DHV) actors and clients. At the start of the project, the project leader Structural Engineering sent a kick-off document
to the design team actors with a proposal for the use of the VDC approach. In a short description of five pages, the kick-off document described two main chapters (DHV, 2009); (1) a brief explanation of VDC and (2) a proposed project specific approach.

The first chapter about the explanation of VDC was meant to introduce VDC to the design team actors. The explanation mainly consisted of the following description: “VDC can best be seen as a combination of integrated design and 3-dimensional work performed by the advisors” (DHV, 2009). Moreover, the three levels Product, Organization and Process were briefly mentioned: “The base of the VDC approach is within the combination of the Product (the building), the Organization and the Process [...] The organization and process are modeled in the same way as the building is modeled” (DHV, 2009).

The second chapter of the kick-off document explained five proposed steps which should be undertaken in order to use VDC during the design process of the project (DHV, 2009):

1. Composing a stakeholder analysis, in order to develop insight into the most important participants of the design;
2. Collectively composing the demands for the garage;
3. Putting the demands into a POP model, which is used to measure and refer the design variants in relation to the PoR;
4. Collectively composing a “Process Interface Map” (PIM);
5. Composing a biweekly preview based on the “Process Interface Map”.

These steps indicate that an organization visualization, process visualization and POP model were planned to be used throughout the process. Although not mentioned in the five steps, the kick-off document described the use of Integrated Concurrent Engineering (ICE) meetings in a meeting room with an interactive SmartBoard. Below, the description of the proposed VDC components and their targeted goals as mentioned in the kick-off document are described.

**ICE sessions**

The kick-off document (DHV, 2009) provided a description of the targeted and expected use of ICE in a meeting room equipped with a SmartBoard. The kick-off document described that the planned ICE sessions consisted of 3D design activity performed by different advisors. The document describes that, prior to the ICE session, 3D models from the architect, structural engineer and installation advisor had to be send to the VDC facilitator. This VDC facilitator was supposed to combine the models after which the models were presented on the SmartBoard during the ICE session. During the ICE session, the combined 3D model was supposed to show clashes between the 3D models of the disciplines after which these clashes could be spoken about during the sessions.

**Organization visualization**

The project organization was supposed to be visualized using a power-influence diagram, as shown in figure 3.3. The aim of this diagram was to provide insight into the stakeholders of the project. More specifically, the diagram aimed to provide insight into the power and influence of the stakeholders
during the design process. The power-influence diagram had to consist of four quadrants: (1) keep satisfied, (2) manage closely, (3) monitor and (4) keep informed. The four quadrants in the diagram were supposed to be used to classify the stakeholders with regard to their involvement in the project.

![Power-influence diagram](image)

**Figure 3.3: Power-influence diagram**

**Process visualization**
The kick-off document (DHV, 2009) described the targeted use of “Process Interface Mapping” (PIM). PIM was defined as the activity of visualizing the process by planning the tasks and actions of individual design team actors. Figure 3.4 shows an example of a PIM process planning. The kick-off document (DHV, 2009) described that the plan was to use handwritten post-its for the planning of tasks and actions of the process. Moreover, one of the interviewees mentioned that PIM was meant to identify task interdependency as well as task deadlines. The plan was to evaluate and update the PIM during every meeting.

**Product model**
The kick-off document (DHV, 2009) described the targeted use of the Product model. The most important requirements for the parking garage were to be defined and placed in a Product model. The Product model was aimed to be used to assess the performance of the design, i.e. to determine to what extent the design meets the requirements.

### 3.3 VDC design approach during the preliminary design process

#### 3.3.1 Actual use of the VDC approach

At the start of the VDC design process the VDC kick-off document was made, which described the intended use of VDC in the design process of the project. The plan was to use product visualizations, organization visualizations, process visualizations, a POP model and ICE meetings in a meeting room with a SmartBoard. When combining all information from the kick-off document, the interviews and the minutes of meetings, it becomes clear what VDC components have been used for the project.
Figure 3.5 provides an overview of the VDC components used during the project. These components are described in more detail in the next sections.

The VDC design process is partially visualized in the timeline diagram in appendix II. This diagram shows a part of the preliminary design process and displays the meetings held and VDC elements used in the project. Also, the diagram shows the involvement of actors during meetings and the moments of interaction by email. As such, the timeline diagram provides a general overview of the VDC design process for the project Parking Garage.

### VDC design approach, project Parking Garage Amersfoort

![Diagram showing VDC design approach](image)

#### Integrated Concurrent Engineering (ICE)
Co-located collaboration in the iRoom

<table>
<thead>
<tr>
<th><strong>Product</strong></th>
<th><strong>Organization</strong></th>
<th><strong>Process</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The design/building</td>
<td>Design team/stakeholders</td>
<td>Design/construction process</td>
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<table>
<thead>
<tr>
<th><strong>Visualizations</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>2D drawings and 3D models of the building</td>
</tr>
<tr>
<td>power-influence diagram</td>
</tr>
<tr>
<td>Process Interface Map (PIM) with actions and tasks</td>
</tr>
</tbody>
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<thead>
<tr>
<th><strong>Metrics</strong></th>
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<tbody>
<tr>
<td>Product model with measurable product objectives and performance values</td>
</tr>
<tr>
<td>not applied</td>
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<tr>
<td>not applied</td>
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</tbody>
</table>

*Figure 3.5: Elements of the VDC design approach used for project parking garage Amersfoort*

### 3.3.2 Product visualization: 2D drawings and 3D models

The kick-off document (DHV, 2009) described that product visualizations were planned to be used during the ICE sessions to support discussions. According to the kick-off document, different “design models” of the architect, structural engineer and installation advisor were meant to be combined and used for presentation and clash detection. Interviews indicate that different types of product visualizations were used:

“We used Sketchup models, 3D drawings... basic 3D drawings”
– architect (VDC project)

“We had 3D renders, 2D drawings and floor plans, we even had Google Earth”
– project leader structural engineering (VDC project)
The interviewees, minutes of meetings and project documents indicate that multiple drawings and models were made by the architect and the structural engineer. As shown in the timeline diagram in appendix II, 2D drawings were used at the start of the design process. The architect made 2D floor plans and 2D cross sections to display the functional design. These 2D drawings showed information about the layout of the parking garage, such as the position of driving lanes, slopes, parking places and the amount of levels. Moreover, the 2D drawings showed the dimensions of the design variants. The structural engineer used the 2D floor plans of the architect to design the structure of the parking garage. First, the structural engineer made a sketch using pen and paper. Later on in the design process, both architect and structural engineer made 3D models. The 3D models from the architect represented in particular the aesthetics of the façade design variants. The architect also kept on working in 2D for the visualization of the floor plans and cross sections. The structural engineer on the other hand, made 3D models which represented the structural design of the different parking garage variants. The traffic engineer made 2D drawings to represent the traffic design.

Both digital 2D and 3D drawings and models from the architects, structural engineers and traffic engineer were used during meetings to support the discussions. For example, the traffic engineer used 2D drawings of the parking garage variants and the surroundings to analyze traffic flows around the parking garage. These analysis drawings were discussed during meetings. The 3D structural design model was printed to 3D PDF. This 3D PDF could unrestrictedly be rotated and elements could be turned on or off, providing the actors with the possibility to investigate the design from any desirable perspective.

![Figure 3.6: Architectural 3D model (Google SketchUp) and structural 3D model (Bentley MicroStation)](image)

Besides the use of the product visualizations to support discussions during meetings, the kick-off document (DHV, 2009) described that the virtual product visualizations of different disciplinary actors should be combined into one virtual model using software applications. Moreover, clash detection was supposed to be used. However, the drawings and virtual models were not combined using software applications and no clash detection took place. The following was said about the use of the 3D models during the design process:
“I would like the architect to use BIM as well, 3D [in a next project] [...] We used Google SketchUp. That doesn’t count. You can’t really call that BIM”

– project leader structural engineering (VDC project)

The architect used Google SketchUp for the production of the 3D architectural design model, while the structural engineer used Bentley MicroStation for the production of the 3D structural design model. Because different software applications were used, interoperability between models was limited; i.e. combination of the models and drawings as well as direct digital data exchange was limited. The architect and structural engineer did not combine their models and exchange data directly. Instead of direct digital data exchange, actors used models and drawings from other disciplines and translated the information to their own model or drawing. For example, the architects used a 3D PDF print of the 3D Bentley MicroStation model from the structural engineers for the production of their own 3D model in SketchUp. In other words, the lack of interoperability between Bentley MicroStation and SketchUp resulted in the fact that the design was drawn and modeled multiple times by different actors.

3.3.3 Organization visualization: power-influence diagram

An organization visualization was made and updated several times during the design process, as shown in the timeline diagram in appendix II. The first start was made during the kick-off meeting, when the design team determined the stakeholder involvement. On the one hand, the design team identified internal stakeholders (from within DHV), such as the advisors and engineers, but also the board of the company. On the other hand, the design team identified external actors (from outside DHV), such as the municipality, neighbors and future users. During the next design team meeting, the stakeholders were placed in a power-influence diagram, as described in the kick-off document (DHV, 2009). As a result of progress in the design process, new insights were gained and the power and influence of stakeholders changed. Therefore, the power-influence diagram was adapted several times throughout the process. The example of the stakeholder diagram in appendix III shows the content of the power-influence diagram. The project director of SSC Facilities mentioned the following about the development of the organization diagram throughout the design process:

“We had several “living documents”. So in the example I gave with all the different stakeholders; that was displayed in a matrix [power-influence diagram] which was shown in every meeting to see if the matrix was still correct or if insights were changed [...] I must say that at a certain moment it [power-influence diagram] appeared to be a stable thing and we did not speak about it every time”- projects director (VDC project)

The minutes of the design team meetings confirm that the organization visualization was mostly discussed during first meetings at the start of the design process. Whereas the power-influence diagram was updated during meetings at the beginning, it was not discussed during the meetings later on and stakeholder involvement was assumed to be rather fixed.
3.3.4 Process visualization: Process Interface Map
The kick-off document (DHV, 2009) described that “Process Interface Mapping” (PIM) was planned to be used for the visualization and planning of the design process. The plan was to make the PIM using post-its and to evaluate and update the PIM every meeting. Interviews and minutes of meetings indicate that the design team indeed used post-its to compose a PIM to visualize and plan the design process. The use and development of the PIM is shown in the timeline diagram in appendix II. At the first design team meeting, an overall planning of the complete project was made which generally described the dates, deadlines and length of the design phases, specification phase, tender phase, construction phase and deadlines. As from the second design team meeting, PIM was used for detailed planning of tasks and actions of the design team actors. During the design team meetings, the design team collaboratively determined the actions and tasks to work out in order to progress with the design. All of these actions and tasks were written on post-its, which were pasted on a wall or sheet of paper. Responsible actors were pointed out for every action or task. Simultaneously, the design team collectively determined a logical sequence of tasks, taking task interdependency into account. Finally, deadlines were allocated to the actions and tasks. Eventually, the actions and tasks for the next three to four weeks were determined and planned. As the design process progressed, the design team switched from using hand written post-its to using digital text boxes in a PDF editor on the computer. This digital version of PIM allowed similar possibilities as the hand written post-its. However, the digital PIM version also allowed more rapid digital sharing within the design team.
Throughout the design process, different types of PIM visualizations were used, as shown in appendix IV. At the second design team meeting the PIM resulted in a Gantt chart planning. The third design team meeting the PIM resulted in a digital display of the post-its as determined during the meeting, a network diagram, a Gantt chart and an action list. After the fourth design team meeting the PIM resulted in an action list. The PIM of the fifth design team meeting resulted in a digital display of the post-its determined during the meeting. As from the third design team meeting the actions and tasks determined in the PIM of the previous meeting were checked for completion. Actions and tasks which were not completed were prolonged or postponed and taken into account when working out the new PIM.

3.3.5 POP metrics and POP model
The kick-off document (DHV, 2009) described that the product metrics would contain the requirements for the building. Purpose of the product metrics was to enable quick assessment of the performance of the design with regard to the requirements. Between the first and the second design team meeting, a POP model was composed by the project leader structural engineering. Only the product section of this POP model was filled in. The requirements for the parking garage mentioned in the memo of SSC Facilities were translated to measurable objectives and demanded objective values for the product metrics in the POP model. An example is shown in appendix V. The translation of the requirements to the values in the product metrics was done collectively by the design team during the second design team meeting. Examples of the measurable objectives are, among others: the amount or parking places, the size of parking places, the orientation of parking places, the
investment costs, the costs for use and maintenance, floor height and accessibility. Demanded objective values were determined for all measurable objectives. Also, weighting factors and qualitative threshold values were described. These product metrics were discussed during the second design team meeting. The design team collaboratively evaluated the product metrics and the decision was made to change some demanded objective values, weighting factors and qualitative threshold values. During the third design team meeting, the product metrics were evaluated by the design team again. The decision was made to change the weighting factors to increase the weight of the investment costs and the costs for use and maintenance. Also, the qualitative threshold values were slightly changed after the third design team meeting. Eventually, the product metrics were used for the assessment of the different design variants for the parking garage. This assessment with the POP model resulted in a scoring histogram which showed what design variant performed best for the chosen measurable objectives. The scoring histogram was used by the design team to explain the preference for the design variant to the board of DHV.

The theory about the VDC approach not only describes the use of metrics for performance measurement of the product, but also for the performance measurement of the organization and the process. However, for this VDC pilot project, no organization metrics and process metrics were used. The design team did not describe and evaluate requirements for the performance of the organization and process. During interviews, the project leader structural engineering mentioned that the description of both measurable objectives and demanded objective values for organization and process was experienced to be difficult. Because of these difficulties and the relatively small size of the design team, the decision was made not to use organization and process metrics for performance measurement. Instead of using metrics, management of the organization and process took place in a traditional manner; e.g. through discussion about issues such as work load, organization capacity and task conformance.

3.3.6 Interaction within the project organization
When looking at the design process, design team meetings were important moments of interaction between the design team actors. During such meetings, actors came together to discuss design progress and design issues. The sub-meetings, emails and telephone conversations were important ways of interaction between the design team meetings. The different types of interaction are described below.

Design team meetings and meeting minutes
The design team meetings were important moments of interaction between design team members. Several design team meetings are displayed in the timeline diagram in appendix II. After the kick-off meeting was held and the kick-off document was sent to the design team actors, the VDC design process started and multiple design team meetings were held in a meeting room with a SmartBoard. The design team meetings appeared not to be ICE sessions such as planned and described in the kick-
off document (DHV, 2009). The project leader structural engineering and the architect said the following about the degree of ICE during the design team meetings:

“We did not really do ICE sessions where you perform integrated design together”
– project leader structural engineering (VDC project)

“Designing during a session did not happen. Refinement or improvement maybe.”
– architect (VDC project)

The interviewees indicate that design activity as described in the kick-off document (DHV, 2009) did not take place during the design team meetings. The drawings and models made by the different advisors and engineers were not combined or used for clash detection and a limited amount of designs were made during the meetings. Although actual design activity was limited, the design team meetings appeared to be used for the discussion and evaluation of the design variants as well as the alignment between the different disciplinary actors involved. Such discussion, evaluation and alignment resulted in examination of several design possibilities. However, these possibilities were never completely designed during the meetings. In other words, no design iterations took place during the meetings.

The minutes of the meetings show snapshots made with the SmartBoard which give insight in the use of visualizations during the meetings. An example is shown in appendix VI. Visualizations of the design variants were used during the meetings, such as floor plans, cross sections and 3D images. The digital presentation of the visualizations allowed the actors to interactively use the models; e.g. turn around 3D models and switch drawing data on or off when necessary. Besides the product visualizations, the design team also discussed the power-influence diagram and the PIM process planning during the meetings. The design team discussed and evaluated issues with regard to the product, organization and process during the meetings and wrote digital comments on the visualizations using the SmartBoard pencil and eraser tools. The issues discussed and evaluated during the design team meetings were captured using snapshots. These snapshots were added to the minutes of the meetings. After the design team meetings, the different actors proceeded working on the design documents based on the comments made and captured during the meeting. Sometimes, additional sub-meetings were arranged by actors to talk about specific items. For example, a meeting between the project leader structural engineering and the traffic engineer was arranged to discuss the accessibility and traffic safety scoring of the design variants.

The issues discussed during the meetings were recorded in the minutes of the meetings. Different formats for the minutes were used throughout the design phase of the VDC project. An example of minutes with the most elaborated format is shown in appendix VI. Basically, the minutes of the VDC meetings consisted of two parts: (1) a textual core part and (2) an appendix with the visualizations. The textual part of the minutes start with a header displaying standard minutes information such as the project name, date, attendees, other actors involved and the date when the minutes were made.
Then, the minutes show the design task list which was determined and planned in the previous meeting. During the meeting, the design task list was displayed on the SmartBoard in the form of a diagram, which was added to the appendix of the minutes. The design team checked whether or not the design tasks from the previous meeting were finished. In case a design task was finished, the status of the task was defined as “finished” and the date of completion was stated in the design task list. For design tasks which were not finished, the status was defined as “not finished” and sometimes “prolonged”. Some design tasks led to new tasks as well. In that case, “new action” was added to the task to show that a new task was identified. These are examples of the design tasks mentioned in the design task list in the minutes:

1) Routing of cyclists – finished at 11-09-2009
15) Aesthetical – not finished, will be worked out when a variant is chosen (prolonged)
8) Soil data – sand soil; soil probing will follow – new design task: geotechnical advice (new action)

After the design task list, the minutes describe the core part of the meetings. In particular at the start of the design process, the organization visualization was discussed during several meetings. The text in the minutes shows the comments or issues which were discussed about with regard to the organization visualization. In the appendix of the minutes, a visualization of the organization, in this case a power-influence diagram, was added. Comments made on the power-influence diagram show that the diagram was discussed during the meeting. The comments were captured with a snapshot which was added to the appendix of the minutes.

Besides discussing the design task list and organization visualization, the design was also spoken about. The issues discussed were again briefly described in the textual part of the minutes. In the example in appendix VI, several issues are described for the different design variants. Again, the product visualizations which were used to support the discussion of the design team were added to the appendix of the minutes. In this case, several 2D floor plans and a 3D model were added to the minutes. This way, the minutes not only described, but also visualized the issues spoken about during the meeting.

Also, the product metrics were point of discussion during several meetings. Points of discussion during the meeting are briefly mentioned in the textual part of the minutes. The visualization added in the appendix of the minutes shows the snapshot of the digital comments which were written on the visualization of the product metrics with the SmartBoard.

At the end of most of the meetings, new design tasks which were identified throughout the meeting were planned using PIM. The visualization of the PIM process planning was added in the appendix of the minutes. Most minutes end with a preliminary date for the next design team meeting.

Interaction outside design team meetings
The design team meetings were important moments of interaction between design team actors. Besides these regular design team meetings, one-to-one meetings were sometimes arranged when
specific issues had to be discussed. In addition to such face-to-face interaction, multiple types of distant interaction were used outside the meetings.

Most of that interaction in between meetings took place by email and telephone. Telephone conversations were used in case of requests for information or in case of questions from other actors. During an interview, the cost advisor gave an example of the architect who called him with some questions about the consequences of design changes for the total costs of the parking garage. Through that telephone call, the cost advisor and the architect were capable to briefly discuss several possible directions, which helped to eliminate several directions.

Besides telephone calls, email was also used regularly as a means of interaction. Emails were send for different kinds of purposes. First, emails were send to keep the other actors updated about decisions or agreements made or about progress of design tasks. As such, emails were used to inform others. Secondly, actors sometimes used email communication to discuss specific design issues. For example, the structural engineer and the advisor geotechnics emailed about the load bearing capacity of the soil and the parking garage foundation. As such, emails were used for discussion and two way communication. Third, email was used to provide other actors with design documents. These design documents were added to the emails as attachment. Among others, drawings of the design variants were send in DWG format or PDF format. The PDF drawings sometimes contained hand written or digital comments. Other documents send by email were minutes of meetings, information about the scoring for the product metrics, memo’s with updates or requirements and cost estimates. From all emails send, more than six out of ten emails contained one or more attachments. Fourth, emails were used by the VDC initiator, the VDC facilitator and the projects director to communicate about the use of the VDC approach for the design process. Sometimes, emails were combined with telephone calls, to support the message in the email.

Besides interaction by email and telephone, the project leader structural engineering and the traffic engineer made use of some sort of video conferencing. The project leader was in The Hague, while the traffic engineer was in Amersfoort. The computer was used to interact verbally as well as visually. An internet application made it possible to share screens. Drawings of the design variants were displayed and the actors could make digital notes on the computer, which were visible for the other actor as well. The project leader and the traffic engineer discussed the traffic flows of the different design variants by means of the video conferencing.

3.4 Concluding remarks
The project Parking Garage Amersfoort was designed by a multi-disciplinary design team composed of actors from multiple departments of DHV. The project functioned as a pilot project in which VDC was used during the preliminary design process. A kick-off document was made at the start of the preliminary design phase which described the intended use of VDC in the project. However, interviews and minutes of meetings showed that not all aspects which were described in the kick-off document were applied during the pilot project.

Throughout the process, the VDC design team made visualizations of the product, organization and process. 2D and 3D product visualizations were made and used to support interaction during
meetings. The actors did not work in one 3D model, but used their own drawings and models. The 3D model made by the structural engineers was used to calculate costs and environmental impact. The organization visualization was especially used in the beginning of the preliminary design phase to determine stakeholder involvement. During the design process, the organization visualization was updated several times. The overall process was planned with a diagram with phasing and deadlines. At a more detailed level, design tasks were planned and visualized using Process Interface Mapping. Also, product metrics were used by the design team to explicitly describe the requirements and to measure the performance of the design variants. Eventually, the product metrics were used to determine a preferred design variant. No metrics for the organization and process were applied. The VDC design team held multiple design team meetings in a meeting room with a SmartBoard. During the meetings, visualizations and metrics were used to support interaction between the actors. Besides textual information, minutes of meetings also contained the visualizations and metrics discussed during the meetings. Between the meetings, actors used email to communicate and exchange project documents. Also, telephone conversations took place to communicate briefly or to explain the documents send by email. Finally, video conferencing was used to communicate verbally as well as visually.
4. Case study non-VDC: NSP Breda

This chapter focuses on the non-VDC case study for this research. The case study project is the development of NSP Breda, which is the new public transport terminal of the city Breda. This project was chosen for the non-VDC case study because it is a large scale building project with a lot of actors involved. It is interesting to analyze the design approach of such a project and compare it to the VDC design approach. This chapter mainly focuses on describing the final design process of the case study project.

The aim of the case study is to identify and describe the non-VDC design process. Non-VDC design processes can be found in different forms. Therefore, the purpose of this case study is not to draw a complete image of the non-VDC design practice, but to function as a mirror which can be used to show the reality of a large AEC project and to identify possibilities and limitations with regard to VDC implementation.

4.1 Case study introduction: NSP Breda

4.1.1 Reasons for the initiation of the project

Project NSP Breda is part of a larger development plan of the city centre of Breda. Project NSP Breda was initiated to transform the current Central Station of Breda into a new public transport terminal. Developments with regard to public transport, such as new bus connections, increasing amount of trains and the development of the HSL (high speed train connection) (ViaBreda, 2011a) have lead to the decision to upgrade and renew the current Central Station of Breda into a new public transport terminal. The goal is to create a hub for all public transportation. Also, the new terminal has to connect the two housing districts at both sides of the railway. Finally, the terminal is required to be integrated with housing and offices to make it a part of the city centre (Brede AAA, 2006). The development of the project NSP Breda is initiated by a consortium of NS Vastgoed, now called NS Poort (Real Estate department of the Dutch railway company), ProRail (Dutch railway management organization), the municipality of Breda, the Province of Noord-Brabant, the Ministry of Transport, Public Works and Waterworks and the Ministry of Housing, Spatial Planning and the Environment (ViaBreda, 2011b). ProRail is acting as delegated project manager for this consortium and is the organization which is responsible for the overall project management.
4.1.2 Development of project NSP Breda

The project went through several project phases, which are visualized in the timeline in figure 4.1. The architectural firm of K. van Velsen was selected to be the architect for the project. The preliminary design phase and the final design phase were tendered separately. Because of the size of the project, the practical decision was made to cut the preliminary design into several sections, e.g. the travelers tunnel, commercial spaces and service areas, railway tracks, terminal entrances, parking deck, housing blocks and office blocks.

Movares, a large engineering consultancy, was selected for the engineering work for the preliminary design. For the urban design for the terminal, the company Quadrat was hired. Together, K. van Velsen, Quadrat and Movares developed a preliminary design for the complete terminal building and surroundings, except for the housing blocks, which were not worked out to the level of a preliminary design. After the preliminary design phase, further engineering and construction of the travelers tunnel was handed over to a contractor. The architect asked ProRail to involve DHV in the project for the design engineering of the other parts of the design, in collaboration with Movares. That way, the experience of DHV with regard to engineering of buildings and the experience of Movares with regard to the engineering of the infrastructural parts of the project were combined. This resulted in the consortium “Brede AAA”, which consists of DHV, Movares and NACO, the latter being a company which is experienced in design of public buildings and flow of traffic and passengers. Because DHV got involved, the choice was made to start the final design phase with an evaluation of the preliminary design made by K. van Velsen and Movares. After this evaluation, the decision was made to change some of the design principles. The Brede AAA and K. van Velsen started working out these adapted design principles into a pre-FD (pre-final design) for the terminal, parking deck and the offices. When the pre-FD was finished and the design was updated to the new design principles, the project actors started with the development of the final design for the parking deck, terminal and offices. Subsequently, the preliminary design for the housing was prepared, followed by the development of the final design for the housing as well. When the final design for the complete project was ready, a phase of cost reduction was held. Then, the specification phase started and the specifications for all parts of the project were developed. The specifications were updated and changed several times. In October 2010 the final version of the specifications was completed and the tendering started. At the moment that this case study is conducted, the specifications for the retail parts of the terminal are developing, as a result of increased insight. These changes will be worked out into a note of information. The total development of the public transport terminal is planned to finish in 2015 (ViaBreda, 2011c).

![Figure 4.1: Project timeline, project NSP Breda](image)
4.1.3 Scope of the case study
The non-VDC case study focuses on the final design phase of the project. The complete final design phase of that part of the project started in September 2006 and ended at July 2007, as shown in figure 4.1. First, the pre-FD was developed, which was finished in January 2007. Afterwards, the final design was developed. A specific focus of the case study is placed in particular on the period between November 2006 and March 2007. This period is chosen as a focus period, because the duration of the focus period is approximately comparable to the focus period of the VDC case study. Also, this part of the final design phase is most rich and complete in terms of available project information. Because the final design phase started with the development of the pre-FD, the design phase of the non-VDC case study is comparable to that of the VDC case study. Also, the start of the design phase is included in both case studies. An assessment was made between comparability of design phases and availability of information, in order to increase the comparability between the two case studies. The final design process for project NSP Breda is partially visualized in the timeline diagram in appendix VII. This diagram displays the period from November 2006 until March 2007 and shows the design team meetings, actor involvement and email interaction.

4.2 Final design phase
The non-VDC case study focuses on the design approach used in the final design process of project NSP Breda. This section provides a brief description of the final design process and the actors involved in the final design phase.

4.2.1 Final design process
The final design phase started with integral design meetings, which were attended by multiple actors from the client, the architect and the engineers. At the beginning, these actors spoke about the organization of the design team; i.e. all actors from the different disciplines were introduced. Also, the actors spoke about issues with regard to the Program of Requirements (PoR) and the design and engineering work. After the first two integral design meetings, the decision was made to arrange separate meetings about the structural engineering work and the installation engineering work. The goal of these separate meetings was to be able to focus especially on specific structural engineering and installation engineering issues. During the final design process, it also occurred that the structural engineering meetings and installation engineering meetings were combined.

4.2.2 Actors involved in the final design phase
The project NSP Breda is developed by many different actors from different companies and organizations. This case study focuses only on the project actors which were involved at the time that the final design process took place. Also, the case study focuses in particular on the level of the actors involved in the design meetings. The main project actors are coming from ProRail, architectural firm K. van Velsen, DHV and Movares. Although some companies collaborated in projects in the past, the interviewees indicated not to know the other project actors personally before the start of project NSP Breda.
A hierarchical display of the project actors involved in the final design process is shown in figure 4.2. The dark rectangles indicate the actors who attended design meetings. More specifically, figure 4.2 shows the involvement of actors in different types of design meetings. All companies and actors are described in more detail below. The timeline diagram in appendix VII shows the involvement of the actors throughout a part of the design process.

Figure 4.2: Organization chart, project NSP Breda

Client consortium
The project NSP Breda was initiated by a consortium from NS Vastgoed, ProRail, the municipality of Breda, the Province of Noord-Brabant, the Ministry of Transport, Public Works and Waterworks and the Ministry of Housing, Spatial Planning and the Environment. This consortium was represented by a steering committee, with project directors from the municipality, ProRail and NS Vastgoed. The steering committee was involved at a higher management level in the project hierarchy and did not attend any design meetings. A project manager from ProRail was involved in the direct project management for the client consortium.
Project management: ProRail

ProRail represented the client and was responsible for the overall project management. As such, ProRail was an important link between the departments and organizations at the side of the consortium of the client at the one hand, and the design and engineering companies and organizations at the other.

The executive project manager was positioned below the steering committee. This executive project manager was involved in the integral design meetings as the chairman of the meetings. No employees from ProRail were involved in the structural engineering meetings or installation engineering meetings. ProRail was informed about the issues discussed during these engineering meetings through the minutes of the meetings, of which copies were send to the executive project manager. Important issues identified during the engineering meetings were discussed in the integral design meetings.

Architects: architectural firm K. van Velsen

The architectural design for the project is made by architectural firm K. van Velsen. The architectural firm had the responsibility to design, draw and specify the architectural aspects of the project. The architectural firm delivered 2D drawings and specifications of the design to the other disciplines. Most collaboration was needed with the structural engineers and installation engineers from DHV in order to align the architectural design with the structural design and the installation design. The architectural firm had a major role in the development of the final design.

The lead architect of the architectural firm was personally involved in the final design process. The architect attended both integral design meetings as well as some of the engineering meetings. Besides the architect, several other employees from the firm were involved in the final design process, such as a project leader. Like the architect, this project leader was involved in the integral design meetings as well as the engineering meetings. When the architect was not present during a meeting, the project leader replaced him. The project leader had the task of chairing most of the engineering meetings, which were held at the office of the architect. Furthermore, project architects were involved in the design process. These project architects performed most of the design production. At the beginning of the final design process, two project architects were involved, later the amount of project architects changed when necessary. The project architects also attended the engineering meetings. One of the project architects was responsible for making the minutes for the engineering meetings. The project architects were assisted by draftsmen for the production of the architectural design drawings. Between the meetings, communication took place by telephone and email. The project leader and the project architects were responsible for most of the interaction by email with other actors in the design team.

Project management Brede AAA: DHV Rail and Stations

The project management of the consortium Brede AAA was performed by a project manager from DHV Rail and Stations. This project manager was responsible for the overall project management for the engineering work of both DHV and Movares. As such, the project manager was involved in
communication at different levels in the project hierarchy. During an interview, the project manager mentioned about his function:

“And my task is to be the project manager. I steer the whole process. So I talk to the client about what needs to be done and to divide this between the partners of the VOF [the engineering consortium Brede AAA] and assure that an integral design is developed in collaboration with the other actors, especially the architect” – project manager Brede AAA (non-VDC project)

The project manager was involved in communication with the project manager from ProRail and the lead architect from K. van Velsen. Also, the project manager was involved in the integral design meetings between the project manager from ProRail, the actors from the architectural firm and the project leaders from Brede AAA. Sometimes, the project manager was also involved in the meetings at the engineering level. Between the meetings, the project manager stayed in contact with project actors at all levels of the project organization hierarchy by telephone and email. For some parts of his work, the project manager was assisted by other employees from DHV Rail and Stations.

Structural engineering: DHV Buildings

The structural engineering work was performed by the department of structural engineering of DHV Buildings. The department of structural engineering had the responsibility to develop the structural design for the complete project. The structural engineers produced 2D drawings and specifications for the total structural design. Most alignment was necessary with the architect, to assure that the aesthetical requirements were met. Also, frequent alignment took place with the installation engineers in order to check for interferences between the structural design and the installations. As such, the structural engineers had a major role in the development of the final design.

The coordination of the structural engineering work was the responsibility of the project leader structural engineering. This project leader attended the integral design meetings and the structural engineering meetings. The project leader was assisted by the lead structural engineer, who performed much of the structural design work and calculations. The lead structural engineer attended some of the integral design meetings and was present during most of the structural engineering meetings. At first, the project leader and the lead structural engineer were the only actors who were responsible for the design. Later on during the final design phase, another structural engineer was added to the structural engineering team. Also, different draftsmen from the department of structural engineering were involved. Later during the design process, draftsmen from the GEC department of DHV in India were involved in the project as well. Contact with the draftsmen in India was mostly performed by Skype, email and telephone. Between the meetings, the lead structural engineer as well as the structural engineer who was involved later in the final design phase had contact with other actors by telephone and email. When issues with a larger impact had to be communicated, the project leader structural engineering got involved. Most communication between the meetings was performed by telephone and email. Interviewees indicated that also communication by means of a fax was applied at the start of the final design phase.
Installation engineers: DHV Buildings

The engineering of the installations of the project were divided into two parts; the first part contained all the installations for the buildings of the project, the second part contained all the rail-related installations. The installation engineers from DHV were responsible for the first part and engineered the installations for the project during the final design process. The installation engineers made the design of the installations and produced drawings and specifications. Most alignment took place with the actors from the architectural firm and the actors from the structural engineering department. The installation engineers had an important role in the development of the final design. The project leader had the main responsibility for the coordination of the installation engineering work. He attended the integral design meetings as well as the installation engineering meetings. The project leader was assisted by an installation engineer for working out the installation design. This installation engineer was not attending any of the meetings. Communication between the meetings was comparable to the communication performed by the structural engineering department.

Conditioning, phasing, rail-related installations and geotechnics: Movares

Compared to the other parts, such as structural engineering and installation engineering, the part conditioning consists of multiple, relatively small parts. The project leader of conditioning described the engineering work of Movares during the interview:

“[…] overhead contact wiring is part of that, permits, environmental research, soil research, research about ducts and piping... what ducts and piping are existing, what needs to be replaced, those kind of things” – project leader conditioning (non-VDC project)

Also, safety at the train platforms and signing is part of conditioning. Related to that is the phasing of the construction of the parking deck, because the parking deck is positioned above the railway tracks and construction of the deck needs to be aligned with the train schedule.

A project leader from Movares was responsible for the coordination of all the conditioning work. Multiple other specialists and advisors were involved in the project for specific parts of the conditioning work. These specialists were involved for a relatively short period of time. The project leader conditioning organized the work of these specialists and advisors and was the contact point for the other actors in the design team. As such, the project leader conditioning was involved in integral design meetings. Incidentally, he was involved in engineering meetings as well, but only when specific details related to conditioning were spoken about. Later during the design process, towards the specification phase, the rail-related engineering work, also called transfer engineering, became important. The project leader conditioning said the following about that:

“That [transfer engineering] is everything that has to do with travelers; traveler information, announcement system, signing, all those kinds of aspects. We do the kinds of installations regarding the public transport terminal. And the building installations for the offices and houses is done by DHV” – project leader conditioning (non-VDC project)
In several organization charts which were made during the specification phase of the project, transfer engineering was visualized as a separate discipline with a separate project leader. However, the situation in practice was that the project leader of conditioning became the main point of contact for the rail-related engineering work as well. The project leader conditioning indicated to be involved in communication by telephone and email in between the meetings in order to coordinate work and solve problems is necessary.

Other actors
During the final design phase, multiple other actors were involved in minor parts of the design. In example, a project leader from Movares, who was responsible for the construction of the travelers tunnel, was involved briefly in engineering meetings in the final design phase. An advisor about urban space was also involved briefly during the final design phase as well as an employee from DHV who was responsible for the management of the requirements for the travelers tunnel. The company LBP was involved in the final design process for advice about the building physics. Because these actors were involved in minor parts of the project, they are not part of the main focus of the case study.

4.3 Traditional design process in non-VDC projects
The non-VDC case study project represents the approach used during traditional non-VDC design processes in the AEC industry. It provides an overview of the characteristics of such design processes, as well as the challenges and problems that occur in traditional practice. The characteristics, challenges and problems identified might influence the implementation of VDC in practice. The traditional non-VDC design process in project NSP Breda and it characteristics, challenges and problems is described below.

4.3.1 Use of design visualizations and visualizations tools
During the final design process of the non-VDC project, different types of visualizations were applied. In the preliminary design phase, the architect hired a visualization company, A2Studio, for the development of a 3D visualization, which is shown in figure 4.3. This 3D visualization was mainly made for presentation purposes and did not contain components (e.g. walls, floors) or layers. The 3D visualization was used throughout the final design process by some of the actors to get insight into the layout of the design; the 3D visualization assisted the design team actors in understanding and interpretation of 2D design drawings. However, the 3D visualization was limited to specific viewpoints or images of parts of the design. Although the 3D visualization offered a 360 degrees view for every viewpoint in the design, the limited amount of viewpoints meant that the design was not completely visible. Because of the limitations of the 3D visualization with regard to the absence of components as well as limited viewpoints, the 3D visualization was only used by actors for orientation throughout the design. The 3D visualization was not used for actual design activity. In other words, the designers and engineers involved in the design process did not develop the design
with the 3D visualization. Instead, more traditional 2D design visualizations were used. Throughout the project, floor plans, cross sections, façade views and details were drawn in 2D.

After the final design phase, the structural engineers decided to make a 3D model for the structural design, which is shown in figure 4.3. The purpose of this 3D structural design model was to increase insight in the structural design. The structural engineers used the 3D model to explain the layout of the structural design to the actors from other disciplines. 2D drawings were extracted from the 3D model as well. Both the 3D model as well as the extracted 2D drawings were used to communicate and align with the other disciplines. Shortly after the structural engineers developed their 3D structural design model, the client hired a company, 3DBlueprint, to create a 3D model as well. This model contained the designs of all disciplines involved in the project and was used to detect clashes between these designs. The clashes identified were updated by the involved disciplines individually, e.g. the architect updated their 2D drawings whereas the structural engineers updated out their 3D model. As such, the 3D model made by 3DBlueprint was mainly used as a snap-shot of the situation and was not used or updated again during the project.

![Figure 4.3: Architectural 3D model (source: A2Studio) and structural 3D model (source: DHV)](image)

During design meetings, paper prints of the 2D design visualizations were used. 2D drawings on paper, such as 2D floor plans, 2D cross sections and details, visualized all parts of the design and were used to support the interaction between the actors during the engineering meetings. The design team actors also made sketches by hand prior to the meetings or during the meetings to visualize parts of the design and to visualize possible design alternatives or solutions. Copies of the sketches which were made or used during the meeting were not shared with the complete design team.

During interviews, the design team actors indicated that communication between meetings also took place frequently, by means of email, telephone, or a combination of both. Because this communication was not face-to-face, sketches were important to support communication outside the meetings. Interviews with actors from the department of structural engineering indicate they often made those sketches by hand, which they scanned and send to other actors by fax or email. The actors from the architectural firm K. van Velsen also used software applications to digitally work out sketches on the computer, which were send to the engineers by email. Later during the design process, all actors increased the use of computer drawn sketches to visualize the design. The sketches were often supported by text in the email or through a conversation by telephone. The lead
structural engineer of the project said the following about the visualization of the design with sketches:

“We started with sketches, making clear the different options, scanning them and sending them to the architect or the installation advisor and talk about that. And the architect returned images mostly [...] I made hand-drawn sketches and later I made digital sketches” – lead structural engineer (non-VDC project)

After a discussion during a meeting or a discussion by email or telephone, the sketched visualizations and comments were translated into computer drawings. Because multiple organizations were involved in the development of the design, different types of software applications were applied for the production of the design drawings and models. The architect used Autodesk AutoCAD for the production of their digital design drawings, while the structural engineering department worked out drawings using Bentley MicroStation. The installation engineers applied Autodesk AutoCAD for their drawings. Because different software applications were applied, the exchange of digital drawing data between disciplines was limited. Nevertheless, interviews with design team actors from different disciplines indicated that some sort of exchangeable file format enabled the design team actors to exchange some of the information digitally. Nonetheless, the usage of drawings from other disciplines was limited. During an interview, the project leader structural engineering mentioned the following about the information exchange by means of drawings:

“You don’t use their information, but you place them under your own drawing and trace the drawing: “There is a column, is that correct? No, the column has to be thicker”. Then you send a comment to the architect that the column should be thicker” – project leader structural engineering

The comment of the project leader structural engineering shows that the department of structural engineering used information on drawings from other disciplines for comparison and alignment. In other words, some use of information of other disciplines took place. Nevertheless, the explanation of the project leader shows that the digital information of one discipline was not directly copied into digital drawings of the other discipline. Actors from different disciplines used different drawing methodologies, which meant that different sets of layers were applied for the production of the drawings. Moreover, actors used different software applications for the production of the drawings. As a result of the different drawing methodologies and software applications applied by the actors, design changes made by one discipline had to be worked out manually by another discipline.
4.3.2 Program of Requirements; changing design requirements

In project NSP Breda, the client was a consortium of multiple organizations and departments of those organizations. All of these organizations and departments were involved in composing the Program of Requirements (PoR) for the project. ProRail delivered a document with requirements in the preliminary design phase. However, according to several actors in the design team, this document with requirements was incomplete. The lead structural engineer of the project mentioned the following about the PoR:

“Well, the PoR in the beginning was a very elaborated document from ProRail. But… it wasn’t specified to the building. So the PoR developed together with the development of the building. So during time, more and more requirements for the building were added.” – lead structural engineer (non-VDC project)

During an interview, the project leader structural engineering also mentioned that the PoR was incomplete:

“Well, now [in project NSP Breda], in the preliminary design phase there was no real PoR. In the final design phase actors asked about it continuously and very late a hotchpotch was thrown over the fence. [...] Based on that we started to design. [...] During meetings, someone said: “Yes, this week someone from NS bicycles is attending the meeting” And he vividly explained the demands for the bicycle parking, while final design was already worked out for three thirds” – project leader structural engineering (non-VDC project)

Both interviewees indicated that some requirements were defined by the client and that a document was available at the start of the design phase. However, the requirements were claimed to be incomplete, which caused a need for updates of the PoR throughout the design phase. During the interview, the project leader structural engineering explained that the changes of the PoR throughout the design phase take place more often, in example through refinement of requirements after the preliminary design is delivered. He mentioned that this should result in a clearly defined PoR at the start of the final design phase. However, the interviews with the architects and engineers show that the PoR was incomplete at the start of the final design phase and even during the specification phase changes took place.

Multiple reasons were given for the incomplete and ambiguous PoR. First, the project manager Brede AAA described that the combination of a train station, parking facility, housing, offices and commercial spaces into one project contributed to the difficult requirement definition. This combination of functions as well as the influence of multiple organizations at the side of the client resulted in difficulties with defining a complete PoR. During an interview, the project manager of ProRail indicated that ProRail, NS Poort and the municipality of Breda had different project goals and different points of views, which were difficult to combine.
Second, the development of a complete and unambiguous PoR was claimed to be difficult because of the long project duration. Because of this long project duration, it was difficult to define requirements for the commercial spaces, as indicated by the project leader installation engineering:

“Commerce is something which is continuously developing. The tenants of those spaces often engage themselves to the rental contract at a very late stage. So they don’t engage a rental contract in 2006 for a space they get delivered in 2011. Therefore, NS is continuously speaking to possible tenants. But before they commit themselves... that takes time. The concept we had for the commercial spaces in 2006 is currently, in 2010, outdated. We have a new concept, new tenants and therefore also a new plan” – project leader installation engineering (non-VDC project)

The explanation of the project leader of installation engineering shows that tenants of commercial spaces wanted to sign contracts at a relatively late stage of the project, which resulted in the fact that requirements for the commercial spaces of the project became clear at a late design stage as well. However, the commercial spaces are closely related to other parts of the design. Therefore, the general outline of the commercial spaces was already designed, based on the PoR. At that moment, the PoR designated a specific position of the design to be allocated for fast-food shops. Later on, as the tenants and the demands of the tenants became clear, the PoR was changed and all commercial spaces had to support fast-food shops. This meant that the installation design had to be changed, because additional oil discharge installations had to be taken into account. The necessity of additional installations influenced the structural design.

A third reason for the incomplete and ambiguous PoR was the economic crisis which occurred during the design process. At the start of the project, the global economy was flourishing. However, when the economic crisis occurred, the overall project feasibility was at risk. During an interview, the project manager from ProRail mentioned that the economic crisis resulted in lower marketability of the project. For example, it appeared to be more difficult to find tenants for the office spaces and buyers for the housing. This lower marketability resulted in the necessity to make changes in order to assure the financial feasibility of the project. Therefore, budget cuts had to take place and both the PoR and the design were changed.

All together, the PoR appeared to be incomplete at the start of the design phase. This remained a problem throughout the design process, because the PoR was changed and elaborated multiple times. At a certain point the decision was made by the architect to freeze the set of requirements and work out the final design based on that frozen set of requirements. Meanwhile, the client proceeded updating the requirements. When the final design was finished, the requirements on which the design was based were changed significantly. Therefore, a review of the final design was held by the client, architect and the organizations from the Brede AAA, to identify the differences between the final design and the updated requirements. During interviews, several interviewees indicated that this review resulted in many review comments. These review comments had to be processed by the design team, which meant that the specification drawings and documents had to
be changed in order to meet the latest requirements. The processing of review comments resulted in a delay of the project.

4.3.3 Client organization and overall project management

The client for the project NSP Breda consists of a consortium of multiple organizations. All of these organizations have a different share and degree of participation in the project. Besides the different share and participation, the organizations involved in the client consortium have different, organizational project goals and interests. The project manager from ProRail, who had the task to align the visions, goals and interests of the client organizations and communicate with the design team, mentioned the following about the client consortium:

“One of the problems is that ProRail is doing the project management [...] and we have a task by law to make these transfers, to make these passenger terminals, to make them work. [...] And NS Vastgoed is there to exploit and develop real estate which is of course making square meters cheap and selling them higher [...] The municipality, their concern is a good spot in the town which makes a sustainable tribute or contribution to the working and life of the city. These different points of view make it very difficult to work together” – project manager ProRail (non-VDC project)

The explanation of the project manager shows that ProRail, NS Vastgoed and the municipality have different interests and different points of focus. Whereas ProRail focuses on the train terminal, NS Vastgoed focuses on the offices and the municipality is mainly concerned about the urban impact of the plan. Although these interests are not necessarily contradicting, the project manager explained that the differences increased the collaboration difficulty within the client consortium. Synchronizing the different perspectives and aims of the client organizations was experienced to be challenging.

During the interview, the project manager gave an example of such a challenge. He explained that the municipality is specifically aiming to finish the project in time, because the project is a political promise. For ProRail, on the other hand, the conditions of the market are important as well and therefore some delay of the project is discussable. For NS Vastgoed, the profitability and marketability is a main point of focus, to assure the project feasibility. This example shows that the organizations emphasize their interests and points of focus. Additionally, the organizations involved in the client consortium consist of multiple departments within their organization. These departments have different department-specific goals as well.

The multi-organizational character of the client consortium caused difficulties with regard to the development of the PoR and the project planning. For example, the PoR remained incomplete throughout the design phases and the initial project planning appeared to be rather optimistic. Moreover, the project manager was replaced several times, which added to the complexity of the project management.
4.3.4 Design team organization; different company cultures and company goals

The design team consisted of multiple companies and organizations. The most important companies were architectural firm K. van Velsen and the engineering consultancy firms DHV and Movares. During interviews, multiple interviewees mentioned that these three companies had a different culture and way of working. The differences were largest between the architectural firm at the one hand and the engineering consultancy firms at the other. During an interview, one project architect mentioned the following about the culture in the architectural firm in relation to the culture in engineering firms:

“The [architectural] design never stops. And I can imagine for DHV that sometimes it is difficult to deal with that because during the specification phase, we were still thinking about getting it right […] The question is, how long can an architect go on? And how all the offices can think along with them at that moment.” – project architect (non-VDC project)

The quote of the project architect shows a difference in design approach between the architects and the engineers. On the one hand, the architects are focused on improvement of the design. On the other hand, the engineers focused more strictly on the budget and the project planning. Although these differences between the companies existed, interviewees from all companies involved were positive about the collaboration. However, time was needed to get used to each other’s culture and way of working. The lead structural engineer had an argument with the lead architect during a meeting, which eventually resulted in more mutual insight. The structural engineer mentioned the following about the argument:

“In the end it might have caused that I got to know him better and that the architect also got to know me. So, at the moment that you have an argument with each other you also get to know each other better. Maybe it also worked positively. It was the only moment that I experienced problems between the architect and myself.” – lead structural engineer (non-VDC project)

“There is a specific approach about how to work with such an architect and that is important with this architect, you need to understand the approach and we still do that. And that results in a good process” – lead structural engineer (non-VDC project)

The explanations of the lead structural engineer show that “getting to know each other” is important for improving the communication and collaboration within the design team. Instead of changing their own working process, the design team actors tried to take each other’s way of working into account. Similar to the cultural differences between the architects and the engineers, there was also a cultural difference between the engineering consultancy firms within Brede AAA. The project leader conditioning explained that Movares, having a history as being part of the NS, has more experience with rail related projects, in which the architect has a less prominent role. DHV on the other hand had more experience with the architectural firm and could therefore communicate with the architect.
more easily. The design tasks were divided in relation to the fields of expertise of both engineering consultancy firms, which meant that DHV had several large design tasks and the work of Movares was divided into many smaller design tasks. The result of this division of work was that actors from DHV were involved for a longer period of time, whereas most actors from Movares were only incidentally involved.

The different company cultures and ways of working were not the only factors that influenced collaboration within the design team. As a result of the involvement of multiple companies, different company goals influenced the collaboration as well. For example, design team companies get individual payments for their work. It could happen that one company already spend most of the budget, whereas the other company is still designing. Moreover, design team companies and design team actors work on multiple projects simultaneously. Work load from all projects has to be divided over the available company organization capacity. At the architectural firm for example, the capacity was rather limited at a certain moment. New employees were attracted in a short period of time, which had to become acquainted with the company, the project and the design. At the structural engineering department, the design was first worked out by only one project leader and an engineer. Later on during the project, an additional engineer was added to the design team in order to perform the increasing amount of design work. These examples show that companies have to deal with their own company management and related issues such as project budgets, organization mutations, organization capacities and company planning. Such issues could impose challenges to the collaboration within the design team.

4.3.5 Project organization hierarchy; management and decision making
The complete project organization consisted of multiple hierarchical levels. Management and decision making was divided over these different levels as well. Whereas the project directors in the steering committee were involved at the client level, the project manager from ProRail, the lead architect and the project manager from Brede AAA were responsible for the management of the project organization. One level below, project leaders were responsible for the management of their specific disciplinary subgroup of architects or engineers. As such, the project leaders were responsible for the determination of the necessary organization capacity. The organization structure and the organization capacity were no explicit points of discussion within the design team. An organization chart was made by the Brede AAA after the final design phase was finished. This organization chart, displayed in appendix VIII, showed all actors who were directly involved in the project, such as the project manager of ProRail, project management of Brede AAA, project leaders from Brede AAA and the architect. Because the organization chart was made by the Brede AAA, the chart was particularly focused on the organization of the engineering consortium. The organization chart did not have an important role in the daily management of the project. Instead, it functioned as a general reference.
4.3.6 Design process management

The design process was planned at different levels of the project hierarchy. Also, different plannings were made at different moments of the design process. Early in the design process, the project management from ProRail agreed about a planning for the project in consultation with the other organizations in the client consortium. This planning was a Gantt chart which provided an overview of the overall project duration, phasing and the milestones. However, within months after the start of the project, it appeared that the planning was rather optimistic and the project would delay for more than a year. Later on, the project planning had to be changed and a new, more realistic planning was made. However, the consortium organizations had different interests, making it difficult to agree on project scope and process planning. The current project manager from ProRail mentioned that the problems with regard to the definition of the project scope influenced the project planning. During an interview, the project manager of ProRail said the following:

“[...] in my opinion it depends on clarity and discipline. That means that it should be totally clear what is the scope of the project, what is in the design and what is in the specifications of the project and what is not” – project manager ProRail (non-VDC project)

During the project process, the scope of the project changed. About those changes, the project manager said the following:

“So be totally clear about what is in and what is out and be totally clear about the consequences in time and in responsibilities” – project manager ProRail (non-VDC project)

Both explanations show that the project manager stresses the importance of a clear definition of the project scope and clear description of the consequences of the changes of this project scope. The difficult definition of the project scope eventually led to changes in the PoR and the planning of the process.

The planning made by the project management from ProRail was focused on the total project. Besides the planning at project management level, the design process had to be planned within the design team as well. Planning of the design process was done by the different disciplines involved separately. In other words, the design team actors did not produce a shared project planning together. Nevertheless, the design work of different disciplines had to be aligned to some degree. Therefore, several deadlines and milestones were communicated. However, further planning of the design process between such deadlines was mainly done by the disciplines separately.

During the final design phase, an employee from architectural firm K. van Velsen made a planning for the final design phase, using Excel. The project leader structural engineering mentioned that no planning was made for the structural design work in the final design phase. It was mentioned that there was no need for such a planning, because the project leader structural engineering and the lead structural engineer were the only two actors involved in the structural design at that moment. Moreover, the planning of the architect was used by the structural engineers during the final design
phase. A specific planning for the structural engineering work was made during the specification phase, because the team of structural engineers became larger.

The plannings were not used during the meetings to plan the design process at the level of individual design tasks. During meetings, problems and progress with regard to the design were discussed, resulting in an identification of the design tasks. The design tasks identified during the meeting were described in the minutes. Instead of allocating the responsibility for design tasks at specific designers or engineers, the design tasks were allocated at company or organization level. In example, design tasks were allocated to ‘architectural firm K. van Velsen’ (KvV) instead of ‘project architect A’, or to the ‘Brede AAA’ (AAA) instead of ‘structural engineer’. This means that no specific individual was made responsible for the design tasks. The project leader structural engineering explained that the project leaders were responsible for the coordination of the design tasks within their group of engineers or designers. During the meetings, no deadlines were connected to the design tasks. During interviews, several project actors indicated that the general code of conduct was to finish design tasks prior to the next meeting. Related to the deadlines of design tasks is the interdependency between tasks. Although the design team actors spoke about the task interdependency during meetings, it was never an explicit point of focus during the final design phase. The project leader structural engineering indicated that eventually, in the specification phase, insight into the working method of other actors caused an increasing focus on planning of task interdependency. In example, it appeared that the lead architect wanted to be personally involved in most decisions about design solutions, although he did not always attend the design meetings. As the project progressed, the actors from other disciplines started to anticipate on that by providing sketches about design solutions prior to design meetings, allowing the project architects to consult with the lead architect. That way, more progress could be made during meetings between the project architects and the engineers.

4.3.7 Interaction within the project organization

Design team meetings and meeting minutes
An important type of interaction within the project organization were meetings. Meetings were held with actors from different levels of the project hierarchy. For example, meetings were held at client level, at project management level, at project leader level and at the level of the engineers. The meetings at client level were attended by people from all the organizations from the client consortium and the project manager from ProRail. These meetings were focused on getting alignment within the client consortium. The project manager from ProRail also met with the lead architect and the project manager from Brede AAA, to discuss larger issues in the project, related to the project scope, project budget and project planning. The project manager from Brede AAA had meetings with the project leaders from Brede AAA to inform the project leaders about information from the client and to talk about the organization, planning and budgets within the Brede AAA. It is likely that comparable meetings took place at the architectural firm as well. Finally, design team meetings took place, in which the design team actors from both the architectural firm as well as the actors from the Brede AAA discussed the design issues that occurred. These design meetings can be
divided into two types of meetings. First, integral design meetings were held with the project manager from ProRail, the lead architect and project leader from K. van Velsen and the project manager and project leaders from Brede AAA. These integral design meetings were held at the office of DHV in Amersfoort and were chaired by the executive project manager of ProRail. Second, engineering meetings were held to talk about specific design issues with regard to the structural engineering and the installation engineering. These meetings were attended by the actors from the architectural firm K. van Velsen and the project manager and project leaders from Brede AAA. The frequency of the engineering meetings differed throughout the project, ranging from once a week up to once in every month. The meetings were held at the office of the architect. One of the project architects explained why the meetings were held at their office:

“Here [at the architect’s office] is the most practical and central way, because some of the advisors are from Amersfoort, some of them are from Utrecht, some are from The Hague, so this is a more central and nice location. And for us it is very practical, because no one has a car to travel, we all need to travel by train. Since our business is close to the station, it is a perfect location. And we have all the drawings here, software and all the things.” – project architect (non-VDC project)

Both types of meetings were held in meeting rooms without digital tools or technology. The most important purpose of the meetings was to point out and discuss issues and problems which came to light during the design process. Also, the meetings functioned as a moment to seek alignment between the work of the actors from different disciplines. The design team actors used mainly 2D drawings on paper to visualize the design. If necessary, sketches were made on these drawings or in an A4 sketchbook to support the discussion. Also, some of the actors made sketches of possible design solutions prior to the meeting and used them to inform the other actors about the possibilities up front. Sometimes, only solutions had to be discussed and a decision had to be made. In other cases, the meetings were also used to develop new design solutions or improve proposed design solutions. This implies that during those meetings, a limited degree of design activity took place.

Some of the actors made personal notes about parts of the meeting. In general, decisions, agreements, actions and tasks were written down in the minutes of the meeting. For the engineering meetings, minutes were made by one of the project architects of K. van Velsen. The minutes from previous meetings were used as agenda for the next meeting. This way, the minutes were used to structure the meetings. Furthermore, the issues discussed during the meetings were recorded in minutes. The layout of the minutes of both the integral design meetings and the engineering meetings were slightly different. However, in general the minutes of both meetings were similar. An example of minutes of the engineering meetings is shown in appendix IX.

The minutes consist only of text and start with a header giving information about the project name, type of meeting, meeting number, date of the meeting, place of the meeting, attendees and recipients of the minutes who did not attend the meeting. This header is followed by the text which represents the description of the meeting. This section is divided into the different parts of the
building, such as the parking deck, bus station, travelers tunnel and offices. These parts of the building were discussed during the meeting subsequently. The minutes describe comments, decisions and design tasks for all these parts. The design tasks get a specific number, which is composed of the meeting number followed by the number of the design task. The design tasks of a previous meeting sometimes return in the minutes of the next meeting. In that case, the design task is displayed in the minutes as red and italic text. Sometimes, an additional indication, such as “prolonged” or “finished” is added to these design tasks. It also occurred that existing design tasks result in new design tasks. In that case, the newly identified design tasks is written in black text, however, the design task number stays the same. Completely new design tasks are written down in black text and accompanied by a new design task number. In most cases, the design tasks are allocated to “KvV” or “AAA”, indicating that the responsibility for the design task lies with respectively the architects or the engineers. This is an example of a design task mentioned in the minutes:

\[
\text{nr } \text{ Task description – task responsibility}
\]

3.3 Investigate what type of corrosion protection should be applied on steel sheet covering. Galvanizing, powder coating, enamel, etc. KVV contacts building physics advisor (LBP)

The minutes clearly show that no specific deadlines were appointed to the design tasks. The minutes end with a proposed place, date and time for the next meeting. The layout of the minutes was changed and elaborated over time. For example, the design tasks numbers were not used in the first minutes; these numbers were started to be used later on. The same applies for the tasks responsibility.

Interaction outside meetings
Meetings were important for discussion and alignment of design work. However, the actors involved in the project also had interaction outside the meetings. Actors from one discipline often worked closely together at one office. For example, the architects not only worked at one office, they even worked in one open space. That was the same for the actors from the different disciplines in the Brede AAA. For example, most of the structural engineers worked at the office in The Hague. Their office had an open character as well. Working at one location, or sometimes even in one open space, enabled actors to work closely with each other. Design issues could be quickly resolved by means of face-to-face conversations. Also, telephone conversations from a colleague could be overheard, which could trigger other actors and meant that sometimes other actors were immediately informed about design issues. Although designers and engineers from within one discipline worked closely together, most of the disciplines were separated from each other by distance. For example, the architects, structural engineers and installation engineers all worked at different locations. Because actors from different disciplines were separated from each other by distance, use was made of fax, email and telephone to interact. Interviewees indicated that main means of communication were email and telephone, or a combination of those two. Emails were used to inform other actors
about decisions and agreements made by others. Also, emails were used to provide other actors with information. Finally, emails were important to ask questions or to send answers to other actors. In case of urgent or complex matters, the actors used telephone calls to support the communication by email. For example, emails with attachments were send to other actors and a telephone call was used to explain the attachments. Different types of attachments were sent by email, such as sketches, minutes of meetings, cost estimates and calculation schemes. Approximately half of the emails contained one or more attachments. When asked about communication by email, most interviewees mentioned the use of email for quick exchange of digital documents. However, several interviewees also indicated that communication by email sometimes appeared to be difficult:

“Well we had a certain moment that there was a problem because I got lost in the emails because every person asked their questions directly to me and at a certain moment I had ten mails a day just only from the structural engineer about the parts of the building that they wanted to solve. So that was sometimes difficult for me to react on that, because we had other work that had to be done, so at a certain moment I said: “ok just pick one person who deals with the communication”” – project architect (non-VDC project)

“Well, my mailbox is always full, I can’t even clean it up. Sometimes I can’t send anything anymore and then I have to clean it up. It’s the culture of emailing, but I think that it also applies for DHV, for us, for ProRail, for everybody, everything goes by email, everything is being fixed, trying to get assurance, like: “I asked you earlier, why didn’t you answer yet?”” – project leader conditioning (non-VDC project)

The explanations of both interviewees show that communication by email is sometimes problematic, especially because of the quantities. Answering the emails requires time and is claimed to be inefficient. The project leader from conditioning also mentioned a “culture of emailing”; emails are send to capture agreements on paper. The possibility of digital information exchange therefore also had a downside for several actors involved in the design process.

4.4 Concluding remarks
The final design for project NSP Breda was developed for a multi-organizational client consortium. ProRail performed the project management and the design work was performed by actors from architectural firm K. van Velsen. The engineering work was performed by the Brede AAA, a consortium of DHV, Movares and NACO. The design team started the final design phase by changing several principles with regard to the preliminary design. This resulted in a pre-FD, which was the starting point for the development of the final design.

The design team mainly used 2D drawings during the final design phase of the project. After the final design phase, 3D models were made by a 3D modeling company and the structural engineers. All design team actors produced their own drawings and models. Because actors used different software applications, digital data exchange was limited and changes had to be made by the actors individually.
Throughout the design process, mainly 2D computer drawings or sketches were used to support interaction within the design team. The actual use of the 3D models remained rather limited. The Program of Requirements (PoR) appeared to be incomplete at the start of the final design phase. During the design process, new requirements were added and existing requirements were changed. At a certain moment the PoR was frozen and the performance of the design could not be checked during the process. At the end of the final design phase the design was compared to the latest version of the PoR and changes were made.

The organization involved in the project consisted of a multi-organizational client consortium and a design team with multiple companies. The client consortium was represented by a project manager from one of the consortium organizations. Throughout the project, the project manager changed several times. It appeared to be difficult to manage the multi-organization client consortium, since all organizations involved in the consortium had different project goals and project scopes. The design team consisted of multiple companies with different cultures and working methods. The total project organization was divided into several hierarchical levels: client level, project management level, project leader level and engineering level. Part of the design team organization was visualized using an organization chart. The design team organization capacity was managed by the project leaders.

The design process was managed at the different levels of the project organization hierarchy. Whereas the project management was involved in planning at broad level, project leaders managed the process planning at the level of design tasks. The overall process was planned and visualized with a Gantt chart planning. Although a more detailed planning of the final design phase was made, the planning at the level of individual design tasks was not visualized. The project leaders of the different disciplines had an important role in the management and planning of these design tasks. Planning of design tasks partially took place during meetings. However, task responsibility, task interdependency and task deadlines were not explicitly defined.

Throughout the project, different types of meetings were held. Whereas the meetings at the project management level focused on larger project issues, meetings at engineering level focused on detailed design issues. The engineering meetings were held at the office of the architect. During meetings, interaction was supported with paper 2D drawings and sketches. Such meetings focused specifically on the alignment between disciplines with regard to the design. Organization and process were not explicit points of focus during the meetings and were only occasionally discussed rather implicitly. Minutes of the meetings consisted only of textual information about agreements, decisions and design tasks discussed during the meeting. The design tasks were allocated to an organization instead of a specific actor and in most cases, no explicit task deadlines were described in the minutes. The general agreement was to finish design tasks prior to the next meeting. Interaction between the meetings took place by means of email and telephone. Whereas at the beginning fax was used to send documents, later on attachments were send by email.
5. Cross case-theory analysis

The previous chapters described the VDC theory, the design approach used in the VDC pilot project and the project characteristics of a traditional, non-VDC project. This chapter consists of a cross case-theory analysis between the theory, the VDC case study and the non-VDC case study. On the one hand, the cross case-theory analysis shows to what extent the VDC approach was implemented in the VDC pilot project. On the other hand, the cross case-theory analysis identifies how characteristics of real-life, large AEC projects might influence the implementation of VDC. Also, the analysis shows whether challenges of large AEC projects could benefit from VDC implementation. The cross case-theory analysis therefore provides an overview of the expected applicability and implementation of the VDC components in real-life, large AEC projects.

5.1 POP visualizations and modeling

5.1.1 Product visualization

The theory about the VDC approach shows that the product visualizations exist of digital, interactive, multi-dimensional CAD models (Kunz and Fischer, 2009). These CAD models are also interoperable or even interrelated, the latter meaning that changes in one model are automatically changed in other models as well (Kunz and Fischer, 2009). The case studies provided insight into the degree of implementation of the VDC product visualizations during the VDC pilot project as well as the traditional, non-VDC project.

First, the case studies provided insight into the different types of visualizations applied during the design processes. Whereas VDC theory describes that product visualizations are preferably multi-dimensional, the VDC design team applied both 2D and 3D drawings. The same applied for the non-VDC project, during which even more emphasis was placed on the use of 2D visualizations. This was partially caused by the fact that 3D modeling was less developed at the start of the non-VDC project than it is today. However, the non-VDC case study also showed that some reluctance exists among actors with regard to 3D modeling. One of the project architects mentioned the following about 3D visualizations:

“For me, I don’t need it [3D visualization]. Because I can see it from the drawings, I can see the problems in it when I see the drawings” – project architect (non-VDC project)

In addition to the fact that the project architect claimed not to need 3D visualizations to understand the design, the architects also mentioned to be reluctant towards 3D visualizations because the software applications often do not support the high level design quality of the architectural firm.
Nevertheless, 3D visualizations were claimed to be a useful tool for people without professional knowledge of design and construction, such as clients. The project architect mentioned the following during an interview:

“It [3D visualization] has a potential to be a very good tool for the people who have less skills to interpret or visualize, let me say to ‘read’ the drawings. It is also a very useful tool for the client” – project architect (non-VDC project)

During the VDC case study, 3D visualizations were also used to present and explain the design to the client and actors from the municipality. The architect mentioned that the 3D visualizations appeared to be useful to support the explanation of the design, because it increased insight.

VDC theory also describes that VDC product visualizations are digital and interactive. The VDC case study showed that indeed use was made of mainly digital visualizations. The digital visualizations were presented on the SmartBoard during the meetings, which offered the possibility to interactively use the visualization. This interactivity was claimed to increase the insight and understanding of the design. During the non-VDC case study, computer-based visualizations were also applied. However, no digital tools were applied during the meetings of the non-VDC project. In other words, the visualizations used during meetings were paper-based. Actors used printed drawings and sketches to support design team interaction. Whereas the digital visualizations offered the VDC design team the benefit of interactively using the design and have a central discussion about design issues, the paper-based documents used by the non-VDC design team appeared to be rather inflexible and less supportive to discussions. Nevertheless, interviewees did not refer to the paper-based design discussions as being inefficient of ineffective.

A third important implementation factor defined by VDC theory is the interoperability or interrelation of the product visualizations of the different disciplines involved in the design team. During both case studies, interoperability between product visualizations was strictly limited. Actors from different disciplines worked in their own drawings or models and used different software applications and drawing methodologies. Therefore, exchange of design data between these drawings and models was mainly limited to manual extraction. For example, no clash detection took place to align digital design data from one model with digital design data from another model. Although clash detection was applied during the non-VDC project, a model was specifically made for this single time that the clash detection was performed. In other words, the models of the different disciplines were not used for this clash detection and exchange of digital data between models therefore did not take place. After the clash detection, actors proceeded to work with their own visualizations. One of the project architects mentioned the following during an interview:
“When you go into the large projects, the first thing you have to do is to make arrangements about which software program you should draw with. [...] Then you also need specific knowledge about drawing in 3D, so you have to educate your own people especially for the project, which is very, very difficult” – project architects (non-VDC project)

The explanation of the project architect shows the importance of making agreements about the use of visualizations. For neither of the case study projects, agreements were made about the type of visualizations, software applications and the drawing methodology. The lack of such agreements resulted in limited applicability of 3D visualizations during the projects. Moreover, the explanation of the project architect indicates the importance of knowledge about 3D visualization and modeling. Without sufficient knowledge and experience, use of 3D visualizations is expected to be limited.

Although the 3D structural design model for the VDC pilot project was not used to exchange digital design data with the architect, the model enabled extraction of quantities from the model. These extracted quantities were used by the cost advisor to check the cost estimate of the design. Moreover, the extracted quantities were used for the calculation of sustainability scores for the POP metrics for the different design variants.

| VDC        | Combination of 2D and 3D visualizations was applied.  
|            | Multi-dimensional visualizations were claimed to be useful for interaction with the client and external actors.  
|            | Digital visualizations offered interactivity which was claimed to increase insight into the design during design team meetings.  
|            | Interoperability between product visualizations was limited; exchange of digital drawing data was performed manually.  
|            | Model quantities were extracted from the model, which was claimed to be useful for checking cost estimates and determination of the sustainability of the designs.  
| non-VDC    | Combination of 2D and 3D visualizations was applied; mainly 2D drawings.  
|            | Architects expressed reluctance about 3D visualizations, because of limitations. Multi-dimensional visualizations were claimed to be useful for interaction with the client.  
|            | Observations indicate possible improvement of meeting discussions; however actors do not refer to the current meeting discussions as being inefficient or ineffective.  
|            | Interoperability between product visualizations was limited; exchange of digital drawing data was performed manually.  
|            | 3D modeling requires agreements as well as knowledge and experience.  

*Figure 5.1: Main analysis results with regard to product visualizations*
5.1.2 Organization and process visualization

According to VDC theory, the organization is visualized with an organization chart, which shows the actors, reporting paths and decision authorities (Kunz and Fischer, 2009). Moreover, modeling factors should be applied to enable simulation of organization and process (Kunz and Fischer, 2009; Kunz et al, 1998). The VDC case study presented the implementation of the organization and process visualization during the pilot project, whereas the non-VDC case study provided insight into the characteristics which might influence implementation of those visualizations.

Instead of using an organization chart to visualize the organization, the VDC design team used a power-influence diagram. Although this power-influence diagram visualized the stakeholders and their involvement in the project, the diagram did not show the reporting paths and decision authorities. Interviewees from the VDC case study claimed to have used the power-influence diagram instead of the organization chart because it was unclear how to apply the organization chart in the project. In particular, the function of the organization chart was experienced to be unclear. Therefore, the power-influence diagram was used instead, which was claimed to be useful for managing the influence of all stakeholders.

The non-VDC case study made clear that management of the complete project organization is divided over different management levels. For example, project managers of different companies were involved in the management of large parts of the project, whereas project leaders were involved in the management of specific disciplinary subgroups. Interviews with the project leaders indicated that management of the organization was mainly performed in a rather implicit way, based on experience. In other words, visualizations of the organization were scarce. However, an organization chart was made by the project manager of Brede AAA, which showed the actors, division in groups and the reporting paths. Although this organization chart provided insight into the organization, the project leaders mentioned not to have used it for the daily management of the project organization.

Besides the organization chart, the VDC theory describes the use of process visualizations, which show the design tasks, task responsibility, task interdependency and task deadlines (Kunz and Fischer, 2009). Moreover, modeling factors are applied for the simulation and analysis of process efficiency (Kunz and Fischer, 2009; Kunz et al, 1998). Both case studies provided insight into degree of implementation of such process visualizations and modeling factors.

Besides a rather basic overall project planning, the VDC design team used Process Interface Management (PIM) to manage and visualize the design tasks, activities and actions within a scope of maximum one month. The use of PIM allowed the VDC design team to develop an explicit visualization of the process, showing the design tasks, task responsibilities, task interdependencies and task deadlines. The project leader structural engineering mentioned the following about PIM:

"You make a complete planning. So you say: “Purpose is to make a preliminary design. How do we define the preliminary design? As a structural engineer I have to do this, as an architect I have to do this; in terms of an end product which I deliver as a deliverable”. That is a
physical object. [...] That is a post-it. “Alright, how do I get there. I need input from the architect”. You are the architect: “When can you tell me that”. Then you paste a post-it “Deliver this information to the structural engineer”. Then you say: “Yes but I don’t know that, then I need that [information] from you”. That is how you work back until there is nothing to decide about and then you can start” – project leader structural engineering (VDC project)

The explanation of the project leader shows how the actors discussed the interdependency of the tasks and the task deadlines. This way, all actors in the design team determined the most optimal work order for the design tasks collectively. The project leader structural engineering claimed that collective planning of the design tasks by means of PIM created actors awareness about the relationship between their own design tasks and the tasks of other actors. In turn, this was expected to increase the sense of the responsibility of actors. The project leader structural engineering of the VDC project said the following about PIM as a means to increase the actor responsibility:

“That is what the concept is for: that someone does not have to explain why he has not finished something because someone else has not finished his task. When he has to do something with the information that I must deliver and I don’t deliver, do you have to explain to the client why you are not finished? Now [in non-VDC projects] you have to do that, but then [in VDC projects] you do not. Because everybody understands that you are not finished because I’m not delivering in time” – project leader structural engineering (VDC project)

As a result of the transparent process visualizations, the design team actors have a clear overview of the tasks, agreed deadlines and responsibility of actors as well as the interdependency of other (subsequent or preceding) tasks. If a design team actor fails to comply with the planned process it is more clear which actor failed to comply and what consequences are expected for other subsequent tasks. Design team actors are not only able to see who is lacking behind; consequences of delays are identified as well and can be managed in advance. The timeline diagram in appendix X shows the task conformance of the VDC design team over a period of three meetings. The diagram shows that about half of the tasks are completed before the intended deadline. On the other hand, the diagram shows that most tasks are finished before the next meeting.

The non-VDC design team did not use such a detailed process visualization for planning of the design tasks. Their process visualization was made at a more abstract level and consisted mainly of phasing and main project milestones. In other words, the non-VDC process visualization did not show explicit task responsibility, task interdependency and task deadlines. Instead, the process planning was monitored by the project leaders of the different disciplines. The timeline diagram in appendix XI shows the task conformance of the non-VDC design team over a period of three meetings. The diagram shows that half of the design tasks are not finished prior to the next meeting or not mentioned in the minutes of the meetings. The non-VDC interviewees indicated that use of PIM could have increased insight in the design process, which could have supported the process management. However, the project leader structural engineering also expressed doubts about
whether or not the architect would agree with the use of PIM for the planning of the design tasks. For example, the architect might be afraid that PIM would limit the time available for the creative design process necessary to achieve architectural quality. During an interview, one of the project architects also explained that the architectural design process requires time and a certain degree of flexibility. In short, some reluctance could be expected when implementing PIM.

The theory behind the organization and process visualization of the VDC approach is based on the VDT method. This method, described by Kunz et al (1998), combines the organization and process visualization, linking actors with design tasks. Moreover, the combination of the organization-process visualization and the modeling factors should provide analysis of organization and process performance. Because the organization visualization which was applied during the VDC pilot project was limited, no combination was made between organization and process visualizations. Since the use of the organization visualization was already experienced to be difficult, the combination of both organization and process into one simulation model will probably be even more difficult to achieve. In addition to that, the non-VDC case study shows that large projects such as NSP Breda can be characterized by changes in the design team composition and unclear project scopes. Taking such changes into account will increase the time and effort necessary for the organization and process simulation modeling. Therefore, it is questionable whether detailed and accurate organization and process simulation modeling of AEC project organizations is feasible.

Besides the issue of modeling feasibility, it is also questionable whether bottlenecks found through simulation modeling can be effectively dealt with by the project organization. The non-VDC case study showed that large AEC projects are often developed by multiple companies, which have specific company goals and company affairs that might contradict with the project goals. Internal company goals and affairs play an important role in the company organization management and might limit the capability of companies to anticipate on the bottlenecks identified as a result of organization-process modeling. For example, if simulation modeling indicates that additional architects are necessary, internal company affairs are likely to prevent the architectural firm to hire new employees immediately. As a result, actual use of modeling factors could be limited.

<table>
<thead>
<tr>
<th>VDC</th>
<th>No organization chart with reporting paths and decision authorities was used; instead, a power-influence diagram was used to show stakeholders and their involvement.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PIM was applied to visualize and plan the design process at the level of individual design tasks; tasks, responsibilities, interdependency and deadlines were visualized.</td>
</tr>
<tr>
<td></td>
<td>The process visualization was experienced to increase insight, awareness and transparency.</td>
</tr>
<tr>
<td></td>
<td>PIM was experienced to be beneficial for task conformance.</td>
</tr>
<tr>
<td></td>
<td>No combined organization-process visualization was made.</td>
</tr>
<tr>
<td></td>
<td>Modeling factors were not applied.</td>
</tr>
</tbody>
</table>

Figure 5.2a: Main analysis results with regard to organization and process visualizations
The organization involved in a large AEC project is divided over different management levels. An organization chart was made, which visualized the actors and reporting paths. The organization chart was not used for daily management of the project organization; instead, management is often performed in an implicit way, based on experience.

The process was visualized only by means of overall process plannings; responsibilities, interdependency and deadlines were not visualized. Design process efficiency could be improved. Possible reluctance could be expected with regard to PIM process planning.

Practical implications limit use of combined organization-process visualizations. Knowledge and experience of organization and process modeling is strictly limited.

5.2 POP metrics

The purpose of the POP metrics is to predict or measure performance of Product, Organization and Process (Kunz and Fischer, 2009). At the start of the project, the design team develops a POP model in which the objectives with regard to the Product, Organization and Process are described. Also, performance values, such as weighting factors and qualitative threshold values are described. Finally, the POP metrics are made for different levels of detail.

During the VDC pilot project, the VDC design team experienced difficulties with the definition of organization and process metrics. Therefore, the use of the POP model in the VDC pilot project was limited to the product metrics. The VDC design team translated the requirements for the parking garage into measurable objectives and defined the weighting factors and qualitative threshold values as described in the VDC theory. According to the theory, the POP metrics can be defined for different levels of detail. However, there are no clear examples of detailed level-C POP metrics in AEC projects.

The VDC design team did not develop POP metrics at a specific level of detail. In general, the POP metrics in the VDC pilot project remained at a rather abstract level.

Whereas the VDC theory describes that the POP metrics should be used for intermediate performance measurement throughout the design process, the VDC design team used the POP metrics for the comparison of different design variants for the parking garage design. The interviewees of the VDC pilot project mentioned that the design variant that scored best was a different one than they expected. Also, the product metrics helped the design team to present the reasoning behind the design choices to the client and the municipality. The projects director and architect mentioned the following about the role of the product metrics in the communication with the client:

“We used the metrics in the board meeting, in which we showed the demands we used and we showed how the variants scored. [...] And during the meeting the weighting factors could be changed on screen. [...] The possibility to change something and see the sensitivity: “Variant six is the best, but when we shift [the weighting], is it completely different or is it the second best variant?” It gives confidence when you have to make a decision and a variant did
not come out as the best variant because you used one factor specifically, but that the scoring is also good for the other factors” – projects director (VDC project)

“It is very important to see why you reached a solution: “It is for these reasons” and not just “We do it like that”” – architect (VDC project)

The answers of the architect and project director indicate that the product metrics were used to support the communication to the client. This provided insight to the client about the reasoning of the design team actors. Also, the product metrics offered the possibility for the client to adapt the weighting factors and analyze the impact of such changes. If desirable, the client could decide to choose a different design variant than proposed by the design team. In that respect, the product metrics increased the influence of the client on the design process.

Besides these positive experiences with regard to client involvement, the project leader structural engineering mentioned that the POP metrics helped the design team during discussions and in the process of making design choices:

“You want to make objective decisions: “Removing this column; will it be more expensive?” One push on the button and you know it [...] So you know the costs. “But will it be more flexible in use?” “Yes.” “Was that important?” “Yes.” “What was more important, the costs or the flexibility?” “Flexibility was more important.” I’m mentioning that now, but in the sheet it goes quickly, because you have filled it in quickly” – project leader structural engineering (VDC project)

The answer of the project leader structural engineering implies that the product metrics enable objective decision making. However, in order to make objective use of the product metrics, measurable product objectives have to be quantifiable. Aesthetic or architectural quality or beauty is difficult to quantify and performance measurement for these aspects is therefore difficult. For those reasons, some reluctance could be expected with regard to the use of product metrics. For example, interviewees from the non-VDC case study mentioned that the architect might be reluctant towards strict design process management. Therefore, it is expected that architects could be reluctant towards use of product metrics as well.

Besides possible reluctance of actors, the non-VDC case study showed that challenges with regard to the PoR might limit the use of product metrics. Throughout the non-VDC design process, the PoR was changed and elaborated continuously. Because the POP metrics are based on the PoR, changes in the PoR lead to changes in the POP model. In other words, the use and effectiveness of the POP model is limited when the PoR is incomplete. On the other hand, the POP model might function as a means to clarify the requirements. For example, iRoom users claimed that the iRoom tools were experienced to be particularly useful for brainstorms and conceptual design sessions. When the iRoom tools are combined with the POP metrics, multi-organizational clients could be supported in their definition of
the project scope, goals and requirements. However, such use of POP metrics does only help to prevent PoR incompleteness and ambiguity as a result of different visions within the client organization. The POP metrics provide no solution for PoR incompleteness and ambiguity as a result of external influences such as late tenancy contracting or an economic crisis, as occurred during the non-VDC project. In other words, the function of the POP metrics as a tool to ensure PoR definition is limited.

<table>
<thead>
<tr>
<th>VDC</th>
<th>Only the product metrics were applied; organization and process metrics were experienced to be difficult to define. Measurable product objectives, target values, threshold values and weighting factors were applied. No different levels of detail were used. Product metrics were claimed to be useful to support communication towards the client. Product metrics were claimed to be useful for making design decisions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>non-VDC</td>
<td>Metrics require quantifiable objectives; aesthetical or architectural objectives are difficult to quantify. Possible reluctance of actors could be expected, because metrics are limited to quantitative measurement. Product metrics and PoR are mutually interdependent; product metrics could support definition of the requirements.</td>
</tr>
</tbody>
</table>

*Figure 5.3: Main analysis results with regard to POP metrics.*

### 5.3 Project organization interaction

#### 5.3.1 Meeting interaction and captured agreements and decisions

**ICE meetings**

The VDC theory describes the use of ICE meetings in an iRoom environment. The VDC theory describes ICE as co-location of the design team professionals who collaboratively perform design activity supported by advanced modeling, visualization and analysis tools (Kunz and Fischer, 2009). The degree of ICE used in the VDC pilot project was rather limited. Because the product visualizations were not interoperable, no clash detection took place. Besides that, actual design activity during meetings was rather limited. Nevertheless, the VDC design team made use of digital modeling and visualization tools to visualize the product, organization and process. Although the design team did not meet in an iRoom with multiple SmartBoards, most meetings took place in a meeting room with one SmartBoard. The interviewees from the VDC project were positive about the combination of the digital visualizations and the interactive SmartBoard:

- “Instead of having everybody looking at his own piece of paper, everybody looks at the board. And sometimes [...] several people were standing around the board. Adjustments were made and saved and the VDC facilitator processed it so we had a clean sheet next time” – projects director (VDC project)

- “It is useful because everybody talks about the same things” – project leader structural engineering (VDC project)
“Also the fact that it is understandable for all the actors. People know what it is about and understand the problem.” – architect (VDC project)

“The iRoom helps to get input, because you hear all comments during such a session. Everybody has an opinion. And that is indeed important” – architect (VDC project)

The combination of the digital visualizations and the interactive SmartBoard was experienced to increase insight and understandability of the design. Moreover, the discussion during the meeting was experienced to be more central than in traditional meetings. The VDC design team actors mentioned that the increased insight as a result of the digital visualizations made their meeting more efficient and more qualitative.

The non-VDC design team relied more on paper based documents, drawings and sketches to support their discussion during meetings. The lead structural engineer from the non-VDC design team mentioned that quite some time was needed to explain the design drawings. When asked if visualizations in the iRoom would support the discussion during meetings, the lead structural engineer said:

“it happened regularly that you made a design with different variants and you had to explain it and indeed time is needed to have everybody understand it. And such a design meeting takes quite some time when that has to be explained. Maybe not only because it has to be explained, that takes a while, but also before everybody understands it, before all arguments are clear which are needed to make a decision. That can be done much quicker. I think that an iRoom might help at the moment that you can walk through a visualization of the building.” – lead structural engineer (non-VDC project)

The structural engineer describes that the visualizations and iRoom tools might improve insight and increase meeting efficiency. Video recordings of structural engineering meetings in the non-VDC project show how paper 2D drawings were used to explain issues during the meetings. Even though the engineering meeting was held in a small group of approximately five or six actors, the visibility of the drawings was limited for some actors because the drawings are always placed in front of the actor working with it. The iRoom offers increased visibility and centrality of design documents. Moreover, the use of digital visualizations in the iRoom could offer more interactivity and could therefore increase the meeting efficiency and effectiveness. However, observations of iRoom meetings showed that actual use of the iRoom tools differed between meetings. It appeared that preparation of the iRoom meeting is an important factor for success; teams with preparation made extensive use of the tools, whereas teams without preparation made almost no use of the tools at all. In other words, the observations of iRoom meetings showed the importance of preparation of the meetings. Moreover, observations showed that proper introduction with iRoom tools is required to take away initial reluctance or uncertainty of actors towards iRoom use.
Although co-location could offer improved collaboration, the case studies showed that co-location of the design team might be difficult to achieve for several practical reasons. First, non-VDC case study interviews as well as interviews with iRoom users showed that some actors are expected to be unwilling to work outside their own office because of traveling time. Especially when companies involved in the design team are located at large distance from each other, actors have to invest large amounts of valuable time for traveling.

Besides traveling time, the actors in the design team also use knowledge and resources of their own company. For example, the structural engineers in the non-VDC project performed design activity at their own office and were therefore able to approach colleagues for support and feedback. Also, the engineers used the information and documentation available at the company. The same applied for the architects, who mentioned to prefer to work at their own office environment because of the availability of information. In other words, actors are to some extent attracted to their company environment. When co-located, actors are pulled out of that environment, which means that support and feedback from within the company is limited.

Third, interviewees in both the VDC case study project as well as the non-VDC case study project indicated that they work on multiple projects simultaneously. For example, the actors work on design tasks for multiple projects every day. Moreover, communication takes place with other actors or stakeholders involved in all of these projects. Co-location requires that actors are committed to one project completely. Therefore, co-location might conflict with the current daily practice at the design and engineering companies.

*Project organization; management and decision maker involvement*

Kunz and Fischer (2009) suggest that no managers are involved in the VDC design process, which means that the design team should be able to perform their work with minimal management oversight. Instead of management involvement, the design team is facilitated by the VDC facilitator and decision are taken by the design team. Although VDC theory is not completely clear about the exact task of the VDC facilitator, Kunz and Fischer (2009) describe that the VDC facilitator has a supporting task towards the design team professionals.

The VDC pilot project was carried out by a design team with a flat organization. Because the projects director from SSC Facilities was close to the client, the projects director had a rather good overview of the aims and preconditions set by the client. Therefore, the design team had sufficient decision making authority in the team. During the VDC pilot project, the role of the VDC facilitator was fulfilled by a structural engineer. The VDC facilitator supported the design team by making sure that a suitable meeting room was available. Besides that, the VDC facilitator was responsible for the management of the VDC components. Although the facilitator did not chair the meetings, he was responsible for the minutes. The interviewees from the VDC pilot project were positive about the involvement of the VDC facilitator.

The non-VDC case study showed that the total project organization is relatively large and spread over different vertical levels in the organization hierarchy. Multiple project managers and project leaders are involved in the management of the project. This organization structure seems to contradict with
the vision described in VDC theory. Because actors are involved at different levels of the project organization, multiple types of meetings were held. This implies that the decision making process is divided over multiple levels as well. As such, detailed design issues are resolved at engineering level, while more abstract project issues are resolved at project management level. In other words, actors at higher levels of the project organizations have limited involvement in lower levels of the project organization. For example, the lead architect of the non-VDC project was not involved in all of the design meetings. During those meetings, design decisions were made by project architects. Those decisions sometimes had to be revised after the project architects had consultation with the lead architect. On the one hand, this example shows that it is preferred to have all decision makers involved during a meeting. Simultaneously, this example shows that it will prove to be difficult to involve all decision makers during all of the meetings.

Minutes; captured decisions and discussions

The VDC theory does not define a particular approach to capture decisions made. The issues discussed and decisions taken during design team meetings are captured in minutes of those meetings. For both case study projects, minutes of the design team meetings were made. These minutes give an overview of the issues discussed during the meetings. Also, the minutes give insight into the approach used during the meetings. Therefore, the minutes are an important source of information to show the differences between the design approaches used for the VDC project and the non-VDC project.

When looking at the minutes of both meetings, several differences can clearly be seen. Whereas the non-VDC minutes solely exist of texts, the VDC minutes also contain images. The textual part of the VDC minutes is rather short compared to the minutes of the non-VDC project. Another difference is that the textual part of the VDC minutes shows no design tasks and responsible actors throughout the minutes. Instead, a design task list is used to display all design tasks of the previous meeting as well as the design tasks defined in the current meeting. Whereas the non-VDC minutes only show deadlines for design tasks occasionally, the design tasks in the design tasks list of the VDC meeting are all connected to a deadline. The most obvious difference between the minutes of both projects is that the minutes of the VDC meetings contain visual information. The visual information consists of digital snapshots made during the meetings. These snapshots capture the drawings and comments made during the meeting, as well as the solutions discussed and the decisions taken. The non-VDC minutes did not contain such visual information; the non-VDC design team actors only had the textual description of the meeting which was composed by the minutes secretary. This secretary captured comments, discussion points, agreements, decisions and design solutions in text. In other words, visual information was translated into textual information. This process not only takes quite some time, translation of visual information into written data is also likely to result in a certain degree of loss of information. Besides that, other actors who read the minutes need to translate the written data into visualizations. This process consists of multiple conversions which all carry a risk of misinterpretation. Because the VDC design team used visualizations in the VDC minutes, these risks are reduced. In general, the VDC minutes seem to capture comments, discussion points, agreements, decisions and design solutions more explicitly than their non-VDC counterparts.
5.3.2 Interaction outside meetings
Actors involved in both projects mentioned that interaction by means of email and telephone were important in between meetings. In both projects, actors used email to update others, to communicate or discuss design issues with others and to provide others with information. Attachments were send by email in both projects as well. When all emails are considered, relatively more emails with attachments are send for the VDC project than for the non-VDC project. However, the difference with the non-VDC project could be caused because both projects were held at a different time. Because the non-VDC project was held several years prior to the VDC project, it could be that fewer emails with attachments were send for the non-VDC project. Especially at the start of the non-VDC project, fax messages were also used to send project documentation. The type of attachments in both projects was similar. Actors from both projects mentioned that telephone conversations were used to support interaction by email if needed. For example, difficult issues were said to be explained one-to-one by means of the telephone. Different from the non-VDC project, the VDC design team also used some sort of conference call to interact between the meetings. A video recording of this call showed how the visual information on screen supported the verbal communication, making the interaction more efficient.

<table>
<thead>
<tr>
<th>VDC</th>
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</thead>
<tbody>
<tr>
<td>The actual design activity during meetings in the iRoom was limited.</td>
</tr>
<tr>
<td>iRoom tools supported the use of visualizations and increased insight and understandability.</td>
</tr>
<tr>
<td>Preparation of iRoom meetings is an important factor of success; introduction of actors with iRoom tools is required.</td>
</tr>
<tr>
<td>The project was carried out in a flat organization hierarchy without involvement of project leaders; the design team had sufficient decision making authority.</td>
</tr>
<tr>
<td>VDC facilitator guided the VDC design process and managed the VDC components.</td>
</tr>
<tr>
<td>Clear VDC minutes were used, which contained explicit visualizations and a clear design task list.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>non-VDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently, co-location is not used and knowledge and experience is limited.</td>
</tr>
<tr>
<td>iRoom tools could offer more profound meetings and could increase meeting efficiency.</td>
</tr>
<tr>
<td>Co-located design activity is expected to be limited as a result of practical issues such as traveling distance and daily practice.</td>
</tr>
<tr>
<td>The project organization was characterized by a hierarchical structure with multiple management levels.</td>
</tr>
<tr>
<td>Presence of multiple management levels contradicts with VDC principles.</td>
</tr>
</tbody>
</table>

Figure 5.4: Main analysis results with regard to ICE meetings and design team interaction

5.4 Summary
This chapter described the cross case-theory analysis between the VDC theory, the VDC case study and the non-VDC case study. A complete overview of the results of this analysis is shown in figure 5.5. The left section of the diagram describes the degree of VDC implementation during the VDC pilot project, as well as the implementation experiences identified during the project. The right section describes the expected implementation possibilities for the VDC components during large, real-life AEC projects, as well as the challenges for which VDC could offer possible benefits.
<table>
<thead>
<tr>
<th>VDC CASE STUDY</th>
<th>VDC COMPONENTS</th>
<th>non-VDC CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A combination of digital 2D and 3D product visualizations was applied. Interoperability between different product visualizations was limited. Model quantities were extracted from the product visualizations and used for check of cost estimates and for calculation of sustainability of the design.</td>
<td>The use of interoperable, digital, multi-dimensional product visualizations is expected to be limited, as a result of different software applications used by the actors involved. Growing experience with regard to 3D modeling might increase implementation possibilities in the future.</td>
<td></td>
</tr>
<tr>
<td>The use of digital and interactive multi-dimensional product visualizations was experienced to increase insight and understanding throughout the complete design process. The multi-dimensional product visualizations were claimed to support interaction with the client and municipality.</td>
<td>Compared to traditional paper 2D visualizations, digital 3D visualizations could increase insight and understanding, in particular when interaction with the client is concerned. However, attitudes, knowledge and experience with regard to digital 3D visualizations differ throughout the disciplines involved in the industry.</td>
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<tr>
<td>No organization chart was applied to visualize the actors, reporting paths and decision authorities. Instead, a power-influence diagram was used to display the stakeholders and their involvement in the design process. No combination was made with the process visualization. No modeling factors were applied. It was claimed to be unclear how to use the organization chart for the pilot project. The stakeholder diagram was experienced to increase insight into the power and influence of stakeholders.</td>
<td>Involvement of multiple management levels in the project organization could limit the use of organization visualizations. Sufficient experience and knowledge is available to implement basic organization visualizations. Further use of organization visualizations, such as the connection with the process visualization or the use of modeling factors for simulation will remain limited.</td>
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<tr>
<td>The design process was visualized with an overall design planning and detailed PIM visualizations. The PIM visualizations showed tasks, task numbers, task responsibility, task deadlines and task idempendency. Different PIM visualization formats were used. No combination with the organization visualization was made. No modeling factors were applied. The PIM visualizations were experienced to create a more explicit overview of the complete design process. Insight into the task completeness and task conformance was gained as a result from the PIM visualizations. PIM was experienced to be beneficial for the task conformance.</td>
<td>Sufficient experience and knowledge is available to implement PIM visualizations. PIM requires additional effort, but is expected to deliver a more explicit and efficient process in return. Stricter planning requires commitment of actors, which therefore is a point of attention. Combined organization-process modeling is still limited, as well as the use of modeling factors.</td>
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<tr>
<td>Product metrics with measurable objects, target values, threshold values and weighting factors were applied. The metrics were used to measure and compare performance of different design variants. The product metrics were not divided over different levels of detail.</td>
<td>The traditional non-VDC process planning is less explicit and leaves room for interpretation. For example, responsibility, deadlines and independence are not always identified. Process visualizations such as PIM offer more explicit deadlines, responsibility and independence.</td>
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<tr>
<td>Metrics were experienced to be a useful tool to compare the design variants and make design decisions. Moreover, the metrics were used to explain design choices to the client.</td>
<td>Translation of the PSt to complete product metrics is expected to be limited to a superficial level of detail. For example, qualitative requirements are difficult to translate to quantitative metrics and such translation might encounter opposition. Also, PSt incompleteness limits metrics use.</td>
<td></td>
</tr>
<tr>
<td>No organization metrics were applied, because it was unclear what measurable objects could be applied.</td>
<td>The PSt for the project appeared to be incomplete and ambiguous. The metrics could function as a tool to support brainstorming to achieve clear insight into requirements. As such, product metrics are in particular useful during definition or conceptual design phases.</td>
<td></td>
</tr>
<tr>
<td>Because not organization metrics were applied, implementation experience is not available.</td>
<td>Because of difficult definition of measurable organization objectives, only superficial implementation of organization metrics is expected to be possible. Special attention should be paid to commitment of actors.</td>
<td></td>
</tr>
<tr>
<td>No process metrics were applied, because it was unclear what measurable objects could be applied.</td>
<td>The presence of design team actors differed (strongly) per meeting. Organization metrics could offer a tool to clearly show the actor attendance during meetings. Awareness could lead to increased attendance of actors.</td>
<td></td>
</tr>
<tr>
<td>Because no process metrics were applied, implementation experience is not available.</td>
<td>Because of difficult definition of measurable process objectives, only superficial implementation of process metrics is expected to be possible. Commitment is a point of attention to avoid reluctance of actors towards process metrics use.</td>
<td></td>
</tr>
<tr>
<td>iRoom tools were used to display visualizations and make comments during meetings. Visualizations were added to the minutes. A VDC facilitator guided the process and performed some tasks which traditionally belong to the PSt. Co-located design activity and design iterations were limited.</td>
<td>Insight into task completeness and task conformance was rather limited. Some tasks were postponed or remained unfinished for several meetings. Process metrics show clearly what tasks are delayed. Such insight offers possibility to approach responsible actors and increase efficiency.</td>
<td></td>
</tr>
<tr>
<td>iRoom tools were experienced to increase insight during meetings as a result of digital, interactive visualizations. Meeting facilitation is an essential success factor, as well as practice to use iRoom tools. The VDC minutes provided a clear summary of meeting discussion points through a combination of text and visualizations.</td>
<td>SmartBoards are rather easy to implement. Although practice is expected to be necessary. However, co-located design activity is expected to remain limited as a result of practical issues. Moreover, design iterations require additional tools, knowledge and experience. The presence of multiple management levels in traditional practice contradicts with VDC principles.</td>
<td></td>
</tr>
<tr>
<td>ICE in iRoom</td>
<td>iRoom tools could offer more insight during meetings through digital, interactive visualizations. Also, a more profound and all actors view the same digital and interactive information. Location could play a role in “getting to know each other”. Adding visualizations to the minutes could help to capture design decisions and decrease misinterpretation.</td>
<td></td>
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</tbody>
</table>

*Figure 5.5: Cross-case-theory analysis results*
6. Conclusions and discussion

6.1 Conclusions

VDC is a design approach which offers several tools and methods which are claimed to increase the performance of the AEC industry (Garcia et al., 2004; Kunz and Fischer, 2009). Although case study research about VDC implementation has been performed, the implementation of VDC in large, real-life AEC projects still remained rather unimpressed. This research aimed to get insight into current VDC implementation. Moreover, the aim was to gain insight into the implementation possibilities in large, real-life AEC projects.

First, a clear overview of VDC was described, based on VDC theory. Then, two case studies have been performed. The first case study project was a VDC pilot project, which was performed by a single company. The second case study project was a large, real-life project which was developed using a traditional, non-VDC design approach. The research continued with a cross case-theory analysis, in order to mutually analyze the cases in relation to VDC theory. The cross case-theory analysis provided insight into the possibilities and limitations with regard to VDC implementation in large, real-life AEC projects as well as the possible fields of improvement of such implementation. First, the conclusion with regard to the implementation of the VDC components is described. Secondly, a general conclusion is given about the implementation of VDC during the design phase of AEC projects.

6.1.1 POP visualizations

VDC theory describes the use of visualizations and models for the product, but also for the organization and process (Kunz and Fischer, 2009). The implementation of the product visualizations is described first. Then, because of their mutual relationship, a combined conclusion is drawn about the implementation of organization and process visualizations.

Product visualization: explicit insight supports discussions, limited data exchange and 3D modeling

The research has shown that complete implementation of VDC product visualizations is expected to be limited in large AEC projects. Whereas the VDC design team already experienced difficulties to reach interoperability between models of different disciplines as a result of different software applications used for the project, the non-VDC case study showed that interoperability within a large real-life AEC design team is an even greater challenge due to the increased amount of actors and organizations involved in the design process. Moreover, it can be concluded that, although first steps are made, technological possibilities of interoperable multi-dimensional modeling are still limited.
Combined with limited modeling experience and possible reluctance of actors, it can be concluded that the use of VDC product visualizations is expected to be limited to a superficial level. Nevertheless, the research showed that use of current digital 2D and 3D drawings could increase insight and understandability. Combined with iRoom tools, digital and multi-dimensional product visualizations could support discussions during meetings, making meeting more profound. Most implementation and value is reached when design team actors make visualization agreements at the start of the design process.

**Organization and process visualization: explicit insight into organization and process, limited modeling**

Based on the cross case-theory analysis, it can be concluded that complete implementation of VDC organization and process visualizations as described in VDC theory is expected to be limited in large AEC projects. Current knowledge, experience and tools offer the possibility to make simple organization and process visualizations. The VDC case study showed that such basic visualizations offer increased insight and awareness about stakeholder involvement and task interdependency. However, both organization and process in large AEC projects are more complex and comprehensive and development of high detailed and combined organization and process diagrams will therefore be a rather extensive task. In addition to that, current knowledge, experience and tools about detailed modeling and simulation of organization and process is rather limited in the current AEC industry. In other words, much effort is required to reach a next level in organization and process visualization and modeling. Since detailed organization and process visualizations are untested in large AEC projects, it is unclear whether the benefits of such visualizations justify the additional visualization effort.

Nevertheless, the research indicated that simple organization visualizations and PIM process visualizations were beneficial for the design process of the VDC pilot project. Moreover, the non-VDC case study showed that improvements could be made with regard to planning and management of the design process. Therefore, it can be concluded that basic process visualizations are likely to be implemented in large AEC projects first. More profound and detailed organization and process visualizations and combination of organization and process visualizations will remain limited to pilot projects, until more knowledge, experience and tools are available.

**6.1.2 POP metrics**

VDC theory describes the use of metrics to measure or predict performance of product, organization and process (Kunz and Fischer, 2009). The conclusion with regard to product metrics is described, followed by the organization and process metrics.

**Product metrics: initial level of implementation reached**

The research indicated that implementation of product metrics in large AEC projects will be limited to a partial implementation. The VDC case study showed that the design team had a rather fixed set of requirements which was translated into product metrics. Instead of measuring performance of
For a single design, the metrics were used to measure performance of multiple design variants. Whereas the set of requirements for the VDC pilot project was fixed, the non-VDC case study showed that the PoR of a large AEC project could be incomplete, ambiguous, or subject to change. Such PoR uncertainties could limit the applicability of the product metrics. Moreover, the VDC case study showed that it appeared to be difficult to differentiate multiple levels of detail for the product metrics. Also, several interviewees indicated that reluctance about the translation of qualitative requirements into quantifiable metrics. In short, it can be concluded that implementation of product metrics in large AEC projects is limited to a basic level of implementation with a limited amount of measurable objectives. Therefore, implementation of current product metrics is most useful during conceptual design phases. Attention should be paid to the preparation of a sound PoR and the translation of product requirements into product metrics. At the same time, product metrics might also be used as a tool to achieve more clarity about requirements during early design phases. A collective approach is important to ensure that the application of product metrics is supported by all design team actors.

Organization and process metrics: limited implementation

Based on the cross case-theory analysis, it can be concluded that implementation of organization and process metrics in large AEC projects is limited to a small amount of measurable objectives. The organization and process metrics were not implemented during the VDC pilot project, because it was unclear what kind of measurable objectives could be defined for the organization or the process. Whereas product metrics can be based on requirements of the client, often no clear requirements are defined for organization and process performance. As a result of progressive understanding and implementation experiments throughout different companies, several initial measurable objectives can be identified to measure organization and process, such as actor attendance and task conformance. However, traditional management of organization and process is performed rather implicitly. In other words, actors are currently not accustomed to explicit measurement of organization and process performance and commitment is therefore an important point of attention. In short, because experience and knowledge is still rather limited and acceptance is questionable, implementation of organization and process metrics in large AEC projects is expected to be limited.

6.1.3 VDC design process, using ICE, iRoom tools and a VDC facilitator

VDC theory described the use of ICE and iRoom tools and the involvement of a VDC facilitator during the design process (Kunz and Fischer, 2009). First, the conclusion with regard to ICE and the iRoom tools is drawn, followed by the conclusion about the VDC facilitator.

ICE in iRoom: providing profound meetings, limited co-location and design iterations

Implementation of ICE during large AEC projects will be limited to more profound meetings, since co-location and design iterations remain difficult to achieve. Based on the VDC case study it can be concluded that iRoom and SmartBoards offer increased insight and make meetings and meeting discussions more profound. In addition to that, the SmartBoards were used to capture decisions and design choices, which was experienced to increase insight into the design and decrease
misinterpretation of minutes. As such, SmartBoards were beneficial for the design process. However, interviews and observations indicated that successful use of SmartBoards during meetings depended strongly on the amount of training with SmartBoard use. Moreover, preparation appeared to be an important success factor for iRoom meetings. Although iRoom tools were beneficial for the meetings, it appeared that design choices were not worked out, which means that multiple design iterations did not take place. This could have been caused by the limited interoperability between product visualizations or limited co-location of actors. Involvement of multiple actors, organizations and companies, as shown in the non-VDC case study, is expected to result in limitation of co-located collaboration, because of additional traveling time and absence of company culture.

Based on the limited possibilities to reach design iterations, as shown in the VDC case study, as well as the practical issues shown in the non-VDC case study, it can be concluded that use of ICE in large real-life projects is expected to be limited. Complete co-located ICE will not be possible in most AEC projects. Instead, implementation will remain limited to a rather traditional type of collaboration with the difference that meetings might be more profound and explicit as a result of the VDC components and the SmartBoards. In order to increase the degree of ICE in the iRoom, interoperability of tools should be increased, availability of tools should be increased, education, training and practice in SmartBoard use should be provided and co-location of design team actors should be stimulated.

**VDC facilitator and project organization structure: contradiction with current practice**

Based on the research, it can be concluded that the role and function of the VDC facilitator contradicts with traditional project management. According to VDC theory, project managers are replaced by a VDC facilitator and project organization levels are replaced by a flat organization structure (Kunz and Fischer, 2009). The non-VDC case study showed that multiple project managers are involved in large AEC projects, at different levels in the project organization hierarchy. Although some overlap exists between the role and function of the VDC facilitator and the role and function of the project manager, a project manager is traditionally focused on steering aspects of budget and time, whereas the VDC facilitator is focused on coaching and facilitating the design team to steer budget and time collectively. In short, it is clear that important differences and contradictions exist between the current situation and the situation proposed in VDC theory. In other words, a significant change is required to reach the situation as proposed in VDC theory, which suggests that a gradual transition is necessary. Meanwhile, the exact role and function of the VDC facilitator in relation to the project management is unclear. Whereas the role of VDC facilitator was performed by a structural engineer during the VDC pilot project, the size and complexity of a large AEC project as well as the involvement of different organizations require the role of VDC facilitator to be fulfilled by a separate actor. A combination between the VDC facilitator and the project management seems logical. However, the implementation of the role of VDC facilitator as well as the flattening of the project organization requires a change in overall management, contracting and attitude in the industry. Until such changes are made, complete implementation of the VDC facilitator as well as the flattening of the project organization are expected to remain limited.
6.1.4 General implementation of Virtual Design and Construction

The VDC case study showed that VDC components were only partially implemented during the VDC pilot project. It appeared that several VDC components, such as metrics for organization and process were not implemented because of implementation difficulties and limited experience. When looking at the non-VDC case study, the implementation of VDC in a large AEC project is expected to be even more difficult, as a result of the additional project size, complexity, duration and actor involvement. It can be concluded that the degree of VDC implementation during the design phase of large AEC projects will remain limited to the first implementation phase of the VDC maturity model (section 2.4), which means that implementation of VDC is expected to be limited to the level of visualizations and metrics. Figure 6.1 provides a more detailed overview of the expected degree of VDC implementation in large AEC projects. The diagram shows three implementation levels which provide an overview of the possible implementation of all of the necessary implementation factors of VDC. Although basic visualizations and metrics can be applied, further development is necessary before a next implementation phase can be started. Whereas implementation of product visualizations and metrics reaches a rather developed level, implementation of organization and process visualizations and metrics remains rather basic. Besides mastering the implementation of POP visualizations and POP metrics, ICE is important to enable VDC. It can be concluded that differences between traditional design-engineering processes and the ICE process cause limited implementation of ICE. Further experiments have to be held as well to increase insight and experience with ICE. In general, it can be concluded that VDC implementation requires a gradual implementation process which consists of small steps.

<table>
<thead>
<tr>
<th>Immediate implementation</th>
<th>Short term implementation</th>
<th>Long term implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible with current tools, knowledge, experience and situation in AEC practice.</td>
<td>Additional tools and experience needed, as well as possible change of culture.</td>
<td>Additional research and knowledge needed.</td>
</tr>
<tr>
<td>Digital, interactive CAD visualizations and models (2D and 3D)</td>
<td>Multi-dimensional modeling (solely 3D) Visualization and modeling agreements</td>
<td>Interoperable and interrelated models</td>
</tr>
<tr>
<td>Basic organization visualizations (actors, reporting paths and decision authorities)</td>
<td>Combined organization-process visualization</td>
<td>Organization-process simulation modeling (modeling factors)</td>
</tr>
<tr>
<td>Basic process visualizations (PIM; tasks, responsibilities, deadlines and interdependencies)</td>
<td>Combined organization-process visualization</td>
<td>Organization-process simulation modeling (modeling factors)</td>
</tr>
<tr>
<td>Initial POP metrics during the conceptual design phase (10 product objectives, 1-3 organization and process objectives)</td>
<td>Increased amount of measurable objectives</td>
<td>Application of levels of detail Use of POP metrics throughout the complete design process</td>
</tr>
<tr>
<td>Use of iRoom tools VDC facilitator support Use of VDC minutes to capture decisions and agreements</td>
<td>Design activity and design iterations during meetings</td>
<td>Co-located collaboration Self-managing design team without project manager involvement</td>
</tr>
</tbody>
</table>

Figure 6.1: Implementation of VDC during the design phase of large AEC projects

Implementing Virtual Design and Construction \ June 2011 \ Paul Schrama
Although the main focus of this research was to identify the current implementation of VDC as well as the expected VDC implementation in large AEC projects, the research also provided insight into the added value which was experienced by actors in the VDC pilot project. Although added value was not experienced for all of the VDC components, the interviewees mentioned that the added value was particularly experienced as a result of visualization. Through visualizations, the VDC components helped to create more explicit insight, clarity and awareness for the product, organization and process. As a result of the increased clarity, VDC design team actors experienced discussions during meetings to be more profound compared to traditional meetings. Moreover, visualizations helped to increase awareness of stakeholder involvement. Also, the design process progressed according to schedule.

The research showed that implementation of VDC in large AEC projects is stimulated and limited by many factors. Although implementation of several VDC components is possible, implementation of the complete VDC approach remains superficial if not impossible. When further effort is considered to increase VDC implementation in large AEC projects, the added value should be taken into consideration as well. Whereas superficial implementation of VDC is possible and is likely to provide added value, detailed implementation of VDC in large AEC projects requires more effort while added value is not yet verified. Therefore, careful consideration between effort and added value of VDC implementation is essential. It should be kept in mind that VDC is not a goal in itself, but a means to increase performance in the industry.

6.2 Discussion
The aim of this research was to provide an overview of the current implementation of VDC and to analyze the possibilities and limitations of VDC implementation during the design phase of large real-life AEC projects. So far, research was limited to case study research about pilot projects. This research attempted to provide a preview of the expected implementation of VDC in large projects and the factors that stimulate or limit such implementation. Therefore, a cross case analysis was performed between a VDC pilot project and a large, real-life traditional project.

6.2.1 Research limitations
The VDC case study provided insight into the current implementation of VDC in a pilot environment. Unfortunately, the VDC pilot project was put on hold during the research and no other VDC (pilot) projects were available for research. This meant that the VDC design process could not be analyzed directly and insight into VDC design team meetings was limited. In other words, the research depended on information gained from interviews with design team actors from the pilot project. Because the project took place within one engineering consultancy firm, the complete design team was composed of employees from within this company. In order to prevent information bias as a result of one-sided views, interview results were mutually compared to create an overview of the degree of VDC implementation. Moreover, observations of meetings from other projects were held
to verify the statements of interviewees about the usability and role of the iRoom tools during meetings. Although mutual comparison of interview findings and observations provided verification of information, absence of possibility to observe VDC meetings directly limited the research. Not only could observation have offered means to verify findings, it could also have increased overall insight into the VDC design process.

The non-VDC case study provided an overview of possibilities and limitations of VDC implementation in large AEC projects. Multiple factors were identified that might influence VDC implementation. The non-VDC case study showed the situation for one specific traditional project. In other words, studies of other projects could have resulted in a different overview of influencing factors of VDC. However, this research was of an exploratory nature and the aim was to provide an overview of the possibilities and limitations which could influence VDC implementation. Although influencing factors might differ from one project to another, the case study identified both general and project-specific factors. This exploratory research did not aim to provide a complete overview of all factors that influence VDC implementation. Instead, the research aimed to provide a first insight to identify the first steps to take to improve implementation. Therefore, the conclusion of the research should be seen as preliminary insights, which should be analyzed and verified by means of further research.

6.2.2 Discussion of findings

The VDC case study demonstrated that POP visualizations were partially applied during the VDC pilot project for the aspects product, organization and process. This is rather different from other case study projects and pilot projects, during which focus was particularly placed upon the implementation of product visualizations and the use of BIM during a project (Garcia et al, 2004; Khanzode et al, 2008; Björklund, 2010). In other words, compared to other research projects, the VDC pilot project focused on general implementation of all POP visualizations and less on product visualizations in particular.

During the VDC case study project, only product metrics were applied. These product metrics were limited to one level of detail and to an amount of approximately twelve measurable objects. This is comparable to the use of metrics described by Garcia et al (2004), who described that the use of metrics remained at a high level of abstraction and was also restricted to 10-15 objects. Whereas the VDC pilot project showed that only product metrics were used, other pilot projects indicate that several organization and process metrics have been implemented as well (Lueck, 2010; Michealsen, 2010). However, these metrics also remained at a superficial level and were restricted to an amount of 1-3 measurable objects. In other words, the difficult implementation of metrics identified in this research is comparable to the findings in other research.

The VDC design team held several ICE meetings, during which design issues were discussed and use was made of iRoom tools. Interviewees indicated that the iRoom tools made it possible to have more profound meeting discussions, as a result of increased insight into the design. Previous research indicated that ICE in iRoom resulted in an increasing amount of meeting time spent on explaining and evaluating the design, whereas time to describe the design was decreased (Garcia et al, 2004). The interviewees from the VDC pilot project did not experience a quicker meeting process. Interviews
with iRoom users showed that ICE meetings were even experienced to last longer than traditional meetings. Although iRoom meetings were experienced not to decrease the meeting duration, interviewees referred to the meetings as being more effective and more efficient.

Although slight differences can be identified between the degree of VDC implementation in the pilot projects, the general degree of VDC implementation among pilot projects is comparable. All other pilot projects confirm the conclusion of this research that general VDC implementation remains superficial. It is therefore fair to conclude that complete implementation of VDC is not expected to be reached in the near future. This research showed that implementation of VDC in large AEC projects will prove to be even more challenging. Because of the relatively large project size, high amount of stakeholders involved, multi-organization clients, multi-level project organization and long project duration, implementation of VDC in large AEC projects will prove to be more difficult, while the added value of the approach is yet to be verified. Garcia et al (2004) described that most professionals who observed VDC use during their case study research, experienced VDC as immature. This research confirms that observation and shows that translation of VDC theories into practice remains difficult. For example, detailed visualization and modeling for product, organization and process requires significant effort. The same applies for the use of multi-level POP metrics. It is therefore advisable to consider the expected added value of VDC in relation to the additional effort required to implement VDC components. Although this research did not aim to provide insight into the degree of added value of VDC, analysis and reactions from VDC interviewees indicated that added value of VDC was experienced because VDC components created a more explicit project process. However, based on the limited size of this research, no final conclusions can be drawn about the added value of VDC. Nevertheless, the research results can be used to provide insights or starting points for further research about the added value of VDC as well as the implementation of VDC during the design phase of projects. Insight into the added value is important in order to determine whether efforts to increase VDC implementation are worthwhile.

Moreover, implementation of VDC should be approached as a gradual process. Transition from traditional design approaches to integrated design approaches requires time to allow change of culture and commitment in the industry. In addition to that, implementation of integrated design approaches such as VDC depend on the development of technology. For example, BIM use will be limited as long as interoperability issues exist. As long as VDC theory is still developing and VDC implementation remains challenging, pilot projects are important to VDC implementation. Pilot environments offer the possibility to practice and gain experience, which is a necessary prerequisite for further development of VDC theory and further improvement of VDC implementation over time. Meanwhile, first superficial VDC implementation might provide design teams with tools to reach a more explicit design process.
7. Recommendations

7.1 Recommendations for improvement of VDC implementation

This research provided insight into the expected degree of VDC implementation in large AEC projects. Whereas some VDC components are ready to be implemented, other components require additional steps. Based on this research and other previous research, several recommendations can be provided for the improvement of VDC implementation. These recommendations can be used by companies, such as DHV, to take the next steps to improve VDC implementation. These recommendations can be divided into several groups:

- VDC components;
- iRoom tools and facilities;
- VDC kick-off meeting and VDC design team meetings;
- General implementation process.

7.1.1 VDC components

Standard component formats

The VDC case study showed that different formats of VDC components were used. For example, the design team applied multiple ways to visualize the process planning. By using different formats of visualizations, the design team was able to determine what type of process visualization worked best. Now that the VDC pilot project is finished, it is recommended to capture the most optimal formats for all VDC components used. That way, a library can be developed with different examples of VDC components, which can be used as a starting point for future VDC projects. This prevents that implementation of VDC components is re-invented for every new project. Moreover, projects might differ and the availability of different VDC component formats offers the possibility to choose a format that connects best to the project characteristics. The VDC component library could be updated after every project, to increase the amount of available VDC component formats over time. Besides capturing VDC component formats, a library could be used to store measurable objectives for metrics which were used during a project.

Agreements about product visualizations

With regard to the product visualizations, the research showed that exchange of digital data between different software applications is still limited. Therefore, it is preferred to work with the same
software applications. If such arrangements are not possible, a general exchange format such as IFC is available. However, not all software is compatible with IFC and exchange of information with IFC standards still results in a loss of information. Besides the technological possibility to exchange digital data, design team actors will need to agree about the methodology used for drawing and the way to exchange the data. Arrangements will have to be made to ensure proper exchange of data. Although both 2D and 3D drawings can be used in combination, most advantages can be reached when all actors work in 3D.

Organization visualizations
Organization visualizations are often not made in current AEC projects and organization modeling possibilities are even more limited. Organization visualizations appeared to be most valuable to create awareness about stakeholder involvement in the beginning of design phase. Therefore, it is recommended to start with the development of visualizations at the start of the design phase. First, a stakeholder diagram could be made, to determine the actors involved in the project and to determine the degree of involvement. Second, an organization diagram should be made, to show the organization of the project team. The organization chart should show the project hierarchy with all of the individual actors (name, abbreviation, function and contact information), their disciplinary subgroups, companies and the lines of communication. The organization visualizations are particularly useful at the start of the design process, to create awareness of the stakeholders and project organization. Moreover, organization visualizations could be useful to introduce new actors and organizations to the organization of the project team. The low variability of organization visualizations mean that it is not necessary to update the organization visualizations during every design team meeting. However, it is useful to keep track of the validity throughout the design process. Moreover, organization visualizations could be used to check attendance of actors.

Process visualizations
The process visualization appeared to be valuable for planning the design process. It is recommended to produce an overall process visualization for planning the process at a general level. At a detailed level, PIM is suggested to be used during every design team meeting. Throughout a meeting various design tasks are defined, which should be noted down at one of the SmartBoards in the iRoom. At the end of the meeting, the design team collectively plans all of the design tasks by means of PIM on a second SmartBoard. The PIM could best be made with a network diagram of tasks and should contain at least the task name, task number, task responsibility, task deadline and task interdependency. At the start of the next meeting, the PIM should be used as a starting point to identify task conformance. Any delay could be noted down in process metrics to determine task conformance per actor during the meeting and show whether actors are lacking behind. Design tasks which are unfinished are noted down in the new design task list and planned in the next PIM.

Combined organization-process visualization and modeling
If software is available, a combination between the organization chart and the PIM process planning can be made by connecting the design tasks to the responsible actors. The amount of connections
per actor gives an idea about the workload per actor. The design team could also add an expected
task complexity to every task, to increase the meaning of the predicted workload. However, careful
consideration should be applied between the visualization effort and the increased insight. The
possibilities to combine organization and process visualizations depend on the software capabilities
and the modeling experience and knowledge within the design team.

**POP metrics**

In order to implement the metrics, it is recommended to start defining various measurable objects,
objective values, weighting factors and threshold values for a rather superficial level of detail. It is
recommended to postpone the use of different levels of detail until more experience is gained and
the design team is acquainted with the metrics. Development of the metrics and filling in the POP
model is recommended to be performed by the design team and client collectively, in order to
ensure commitment of actors to the outcome of the metrics. Comparable to the organization-
process modeling, attention should be paid to the balance between effort and added value.

### 7.1.2 iRoom tools and facilities

This research showed that co-location could prove to be difficult to reach. In order to increase co-
located collaboration, several improvements of the iRoom tools and facilities are recommended. The
iRoom tools and facilities are important for co-located collaboration. Insufficient availability of tools
could limit the commitment and possibilities for co-located collaboration.

First of all, it is necessary to create an overview of the software necessary for the iRoom visitors.
General software should be available at the iRoom computers. Moreover, an iRoom network should
be available, which can connect the iRoom computers, SmartBoards and guest laptops. Moreover,
the research showed that internet is used during iRoom meetings, which means that the iRoom
network should offer an internet connection for all iRoom users. Compatibility with both guest
laptops and internet ensures that users can use the software applications they are accustomed to.
Moreover, users can access online databases with information. Access to familiar software and data
is positive for co-located collaboration. Also, design process efficiency is expected to benefit from
software and data accessibility, because less time is needed to search data or get acquainted with
different tools.

Observations of iRoom meetings showed that one SmartBoard was often used to display and present
information, whereas another SmartBoard was used to keep a list of typed notes. Flexibility of the
iRoom could be increased by adding wireless controls of the SmartBoards. Also, iRoom users should
be able to perform SmartBoard take-over to share information from a laptop to the design team via
the SmartBoards.

Observations of several iRoom meetings also showed that different room layouts were used, which
had specific advantages and disadvantages. For example, during one of the meetings, an iRoom
layout was used with a traditional setting with several long rows of tables. This meeting showed that
not many participation took place. For another meeting, tables were placed at the walls of the room
and a circle of chairs was made. This meeting seemed to show more actor participation, but absence
of tables limited the actors in their ability to work with a laptop. In short, it is recommended to take
iRoom layout into consideration when preparing the meeting in the iRoom. When co-located collaboration is aimed for, it is recommended to offer possibilities for actors to work in subgroups. For example, separate groups of tables could be used for companies involved. It should also be considered to add one or more separate meeting rooms which allow actors to retreat and talk in a more private setting.

Finally, traveling time was mentioned as a possible limiting factor of co-located collaboration. Actors mentioned that traveling time would be accompanied by increased cost of traveling. However, co-located collaboration means that more time is spend compared to an usual meeting. Depending on the frequency of co-located collaboration sessions, traveling time and cost could vary. If traveling time appears to be an important issue, it could be considered to create additional iRoom tools and facilities in other parts of the country.

In general, iRoom tools and facilities should be analyzed through the mind of both internal (company) and external users. The iRoom should offer a flexible and optimal working environment for such users, to encourage actors to work in the iRoom. Encouragement is important, because otherwise actors might experience iRoom tools as a limiting factor. In that case, the iRoom tools might increase actor reluctance towards co-located collaboration.

7.1.3 VDC kick-off meeting and VDC design team meetings
Case study insights showed that a kick-off meeting is important to introduce VDC to the design team. During the VDC pilot project, a kick-off document was provided and a presentation about VDC was given to the design team. It is recommended to expand the VDC introduction and organize a VDC kick-off meeting at the start of a project. Such a kick-off meeting should take place in the iRoom and should introduce VDC, the VDC components, the aim of the components and the proposed use of VDC throughout the project. It is important that the complete design team is committed to use the proposed VDC components. Besides introduction of VDC, it should be kept in mind that most design team actors are inexperienced in SmartBoard use. Therefore, actors should be introduced to SmartBoard use and should be allowed to practice with SmartBoard use in an informal way. After VDC introduction, the design team should start to develop first versions of the VDC components. At least the organization visualizations, by means of a stakeholder diagram and an organization chart can be developed collectively during the first meeting.

In order to be effective, the use of the VDC components throughout the design process has to be determined and planned in advance. It is recommended to prepare the subsequent VDC design team meetings and develop a meeting format which describes the role of the VDC components during the meetings. It is suggested to use POP visualizations during every meeting. For example, the design team meeting could start with the organization visualization to keep track of the attendance of actors. Subsequently, the PIM process visualization could be used to check the task completeness and task conformance. Afterwards, specific design issues could be discussed, supported by various design visualizations. Although use of digital design visualizations is recommended, it should be kept in mind that some actors might want to use paper drawings as well. During the discussion of the design issues, new design tasks and agreements might come forward which are planned in a new
PIM. When a co-located ICE session with multiple moments of discussion is held, a distinction should be made between short term and long term tasks. Short term tasks are to be resolved at the same day, whereas long term tasks are planned in the PIM. The POP metrics might be used in a lower frequency, depending on the type of metrics. For example, general metrics to measure actor attendance and task conformance might be applied during every meeting, whereas product metric could also be applied at fixed milestones during the design process. Experiments will have to point out when metrics will have to be applied.

With regard to the minutes of the meetings, it is recommended to use the minutes format which was applied during the VDC pilot project. The combination of texts and visualizations appeared to be useful to capture design issues which were discussed about during meetings. In combination with standard VDC components formats, VDC minutes can provide a clear overview of the design decisions and agreements made during the meetings.

When implementing VDC in a large project, the project organization is divided into multiple levels. The multi-leveled project organization of a large project results in the presence of multiple project managers and project leaders. It is recommended to develop an approach before the start of a design process, which defines the role of the VDC components at all of the levels of the project organization. Moreover, the role of the VDC facilitator in relation to the project managers and project leaders has to be defined.

7.1.4 General implementation process

This research showed that implementation of VDC is a gradual process, which is reached by taking small steps at a time. It is recommended to consolidate the current implementation status and experiences, by translating the lessons learned into updated VDC starting documents, such as a VDC guideline and examples of VDC component formats. Further experience and knowledge about VDC implementation should be gained by conducting several pilot projects. It is recommended to use pilot environments to slowly increase implementation by experimenting with different VDC component formats and increasing complexity step by step. Gradual increase of VDC implementation is preferable, since VDC requires significant change of the current design approach and commitment of actors needs to grow. Because further implementation of VDC is expected to require a significant amount of effort, it is recommended to keep an eye on the balance between the required effort and the expected added value.
7.2 Recommendations for further research

The development of VDC would benefit by future research which focuses on two main aspects. First, research should focus on the added value of VDC compared to other design approaches. As long as the added value of VDC is not verified, it remains uncertain whether or not effort to implement VDC is justified and companies will remain reluctant towards necessary investments. Further research should therefore focus on increasing the amount of pilot projects at companies in the industry. These pilot projects offer an important source of information necessary for further development of VDC. When sufficient pilot projects are available, an objective comparison between VDC pilot projects and traditional approaches should show whether or not added value of VDC can be verified. Instead of focusing on the complete VDC approach, further research should focus on a limited amount of VDC components in particular. Such focus offers the possibility to specifically come to conclusions about the added value of individual VDC components.

Second, further research should focus on the steps to take to reach VDC implementation. Clearly, a gap exists between theory and practice which needs to be bridged. Previous research provided the VDC maturity model, which contains three main phases in VDC implementation (Kunz and Fischer, 2009). However, very large differences exist between the different implementation phases. Research shows that implementation of VDC appeared to be difficult (Garcia et al, 2004; Khanzode et al, 2008). Therefore, future research should focus on the first implementation phase and provide smaller steps that enable easier implementation of VDC. Pilot projects are essential to provide insights into encountered problems and difficulties when implementing VDC. Now the CIFE VDC certificate course program is running for several years, participating companies have performed pilot projects which can be a useful source of information for further research.

When looking at research and pilot projects conducted so far, it becomes clear that multiple ways exist of how to use the VDC components. For example, organization visualizations have different shapes and forms, from power-influence diagrams to organization charts. The same applies for process visualizations, which are used in different shapes and forms as well. Moreover, VDC certificate program documents describe different shapes and forms of VDC components than VDC theory. On the one hand, this shows that VDC offers a degree of flexibility, i.e. the VDC components can be adapted to a particular situation when necessary. On the other hand, it shows that VDC theory is still developing and leaves room for interpretation, which could lead to incorrect use of the VDC components. Further research should clarify the precise purpose of the VDC components. Moreover, further research should develop VDC theory and examples of application of the VDC components should be provided. For example, measurable objectives for the metrics could be provided to give an idea about the possibility to use metrics for the product, organization and process. Besides application of the VDC components, research should point out how VDC components are used throughout the design process.

Both added value and steps of implementation can be researched by means of pilot projects. Continuous tuning between pilot projects and theory could be used to further shape and develop VDC theory.
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June 2011

Paul Schrama


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Appendices

Appendix I  Interview diagram
Appendix II  Timeline diagram VDC
Appendix III Organization visualization: power-influence diagram
Appendix IV  Process visualization
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Appendix VI  VDC minutes
Appendix VII  Timeline diagram non-VDC
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Appendix IX  non-VDC minutes
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Appendix XI  Timeline diagram task conformance non-VDC
### VDC CASE STUDY INTERVIEWS

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*Interview performed by:

PS: P. Schrama  
KEB: K.E. Bektas MSc
SYMBOLS

Design Team Meeting (DTM)

Email interaction

ABBREVIATIONS

AM - Amersfoort
EN - Eindhoven
TH - The Hague
Parking garage Amersfoort, PD phase (6-8-2009 until 3-12-2009)
Appendix III  Organization visualization: power-influence diagram
For reasons of anonymity, names of actors have been replaced by "Name of actor"
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<td>4 days</td>
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<td>Wed 07/10/09</td>
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</tr>
<tr>
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<td>0%</td>
<td>Wed 07/10/09</td>
<td>Actor</td>
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<tr>
<td>20</td>
<td>Terreinmodel opzetten</td>
<td>7 days</td>
<td>Thu 01/10/09</td>
<td>0%</td>
<td>Mon 12/10/09</td>
<td>Actor</td>
</tr>
<tr>
<td>21</td>
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<td>3 days</td>
<td>Wed 07/10/09</td>
<td>0%</td>
<td>Mon 12/10/09</td>
<td>Actor</td>
</tr>
<tr>
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<td>Wed 07/10/09</td>
<td>0%</td>
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<td>Actor</td>
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<tr>
<td>23</td>
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<td>0%</td>
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<tr>
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<td>Beplaging initiële kosten</td>
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<tr>
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<td>27</td>
<td>TCO beplaling</td>
<td>2 days</td>
<td>Tue 20/10/09</td>
<td>0%</td>
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<td>28</td>
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<td>0%</td>
<td>Mon 26/10/09</td>
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<tr>
<td>29</td>
<td>Meeting 4</td>
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For reasons of anonymity, names of actors have been replaced by "Name of actor"
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<td>??</td>
<td>??</td>
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<td>Name of actor</td>
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<td>07/10/2009</td>
<td></td>
<td>Name of actor</td>
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<td>B1, D1)</td>
<td></td>
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<td></td>
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<td>Name of actor</td>
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<td>Name of actor</td>
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For reasons of anonymity, names of actors have been replaced by "Name of actor"
### Appendix V

#### Product metrics: POP model

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<tr>
<th>Function</th>
<th>Verantwoordelijke (Key)</th>
<th>Gedaagd</th>
<th>Waargenomen</th>
<th>Kwalificaties (crisp values)</th>
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<table>
<thead>
<tr>
<th>Product</th>
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<th>Protect Scope (Space, System)</th>
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<tbody>
<tr>
<td>Building systems</td>
<td>Building spaces</td>
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<table>
<thead>
<tr>
<th>Meubels</th>
<th>Vaardigheid</th>
<th>Waarde doelstelling</th>
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<tbody>
<tr>
<td>Voldoening aan eisen</td>
<td>60</td>
<td>57.8</td>
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<tr>
<td>PERK</td>
<td>150 (max)</td>
<td>150</td>
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<tr>
<td>Kosten (totaal)</td>
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<td>500/500</td>
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<td>Gebouw / Kosten (underfoot TCD)</td>
<td>200,000 per m²</td>
<td>200,000 per m²</td>
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<td>Duurzaamheid</td>
<td>Jaar</td>
<td>Jaar</td>
</tr>
<tr>
<td>Wetenschap</td>
<td>Jaar</td>
<td>Jaar</td>
</tr>
<tr>
<td>Betaaldheid</td>
<td>Jaar</td>
<td>Jaar</td>
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<tr>
<td>Persoonlijkheid</td>
<td>Jaar</td>
<td>Jaar</td>
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<tr>
<td>Hoogte</td>
<td>2,30 m</td>
<td>2,30 m</td>
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<tr>
<td>Maximum lengte</td>
<td>24,50 m x m²</td>
<td>24,50 m x m²</td>
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<td>Overlapping</td>
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<table>
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<th>Organisation Form (Act)</th>
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<tr>
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<td>Designers</td>
<td></td>
</tr>
<tr>
<td>Constructors</td>
<td>Constructors</td>
<td></td>
</tr>
<tr>
<td>Owners</td>
<td>Owners</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meetbare organisatie doelstellingen</th>
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</thead>
<tbody>
<tr>
<td>Conformance (time assignment) (t)</td>
<td>100</td>
</tr>
<tr>
<td>Cost (€)</td>
<td>40</td>
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<tr>
<td>Actie duration (d)</td>
<td>5</td>
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<table>
<thead>
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<th>Process Functional Requirements</th>
<th>Responsible Actor</th>
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</thead>
<tbody>
<tr>
<td>Approve. design/construction</td>
<td>Owners</td>
<td></td>
</tr>
<tr>
<td>Approve. design/construction</td>
<td>Approve. design/construction</td>
<td></td>
</tr>
<tr>
<td>Design: Building elements</td>
<td>Designers</td>
<td></td>
</tr>
<tr>
<td>Design: Building systems</td>
<td>Designers</td>
<td></td>
</tr>
<tr>
<td>Build: Building elements</td>
<td>Constructors</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meetbaar proces doelstellingen</th>
<th>Waarde doelstelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety: Injuries &amp; Incidents</td>
<td>0</td>
</tr>
<tr>
<td>Peak Quality Risk</td>
<td>0.25</td>
</tr>
<tr>
<td>Conformance (actual schedule to plan) (%)</td>
<td>80</td>
</tr>
<tr>
<td>Peak Predicted Schedule Risk (risk)</td>
<td>2</td>
</tr>
</tbody>
</table>

| Project | Project goodness | 37 | 100 |

**Legend**

- A variable whose value is not yet predicted
- Automatically calculated
- Not applicable
VERSLAG

Vergadering : Parkeervoorziening Amersfoort
Datum vergadering : 01 oktober 2009
Aanwezig : Names of actors

Afwezig :
Kopie : Names of actors
Dossier : VDC nieuwbouw garage DHV Amersfoort

Ons kenmerk : 91450-71-449
Datum : 02 oktober 2009
Status : concept

Actiepuntenlijst vorige vergadering:

1) Fietsrouting – Afgerond op 11-09-2009
2) Luchtkoker – Wordt niet meer gebruikt – Afgerond op 11-09-2009
3) Toegang project - geregeld, indien andere mensen toegang nodig hebben via [...] – Afgerond 17-09-2009
4) Projectschijf – geregeld O:\AMF_PM\C8240 – afgerond 17-09-2009
5) Update ontwerpvarianten – Afgerond op 17-09-2009; uitvergadering en constructief ontwerp zijn wat wijzigingen gekomen, deze worden verwerkt. (nieuwe actie)
6) Brandweereisen – contact met brandweer ligt gevoelig, punt blijft staan. Actie [...] (aanhouden)
7) Ini'titvergunning – vergunning is er nog – Afgerond 30-09-2009
8) Grondgegevens – zandgrond, sonderingen volgen – komt nieuwe actie voor geotechnisch advies (nieuwe actie)
9) Constructief ontwerp – Afgerond 25-09-2009 - uit vergadering zijn wat wijzigingen gekomen, deze worden verwerkt. (nieuwe actie)
10) Input bereikbaarheid – Afgerond 30-09-2009 - uit vergadering zijn wat wijzigingen gekomen, deze worden verwerkt. (nieuwe actie)
11) Scoring duurzaamheid – Afgerond 30-09-2009 - uit vergadering zijn wat wijzigingen gekomen, deze worden verwerkt. Tevens wordt manier van meten duurzaamheid nog verder onderzocht (nieuwe actie)
12) Omzetten naar vakbreedte van 2,4 meter – Afgerond 28-09-2009 – Dit worden nieuwe varianten die worden meegenomen in het POP model (nieuwe actie)
13) Input kosten – Initiële kosten afgerond, TCO moet nog gebeuren, verder nog verwerken van kosten raming P4A en Betonson offerte laten maken voor Parksyst (nieuwe actie)
14) Scoring bepalen - Afgerond 30-09-2009 - uit vergadering zijn wat wijzigingen gekomen, deze worden verwerkt. (nieuwe actie)
15) Esthetisch – niet afgerond, wordt pas opgepakt als variant gekozen is (aanhouden)

Analyse Stakeholders

- Brandweer Amersfoort vereist aandacht om deze tevreden te houden.
- Gemeente Amersfoort verplaatsen naar 'in de gaten houden'
- Contact geweest met gemeente Amersfoort vergunningen over de plannen, medio oktober volgt de terugkoppeling.
- Duurzaamheid Adviseur toevoegen bij groep 'op de hoogte houden'.

For reasons of anonymity, names of actors have been replaced by "Name of actor"
Macht-invloed diagram van stakeholders wordt aangepast door [...]

Analyse bouwkundige ontwerpen

Bij alle varianten de ‘afsnijd-route’ van het fietspad naar de fietsenstalling onder het D-gebouw dichtzetten.


A-2: Aantal plekken te veel geteld bij in- en uitrit op BG en laag 1, hierdoor 10 plekken te weinig bij deze variant.

B-1: In- en uitrit wisselen, hierdoor qua bereikbaarheid een betere routing. De garage met 1 stramien uitbreiden waardoor de 11 ‘dure’ plekken buiten de garage op het talud bij de inrit van de garage onder het D-gebouw niet noodzakelijk zijn.

C-1: Mogelijkheden vergroten garage besproken.

C-2: Spiegelen over breedte as, zodat je garage binnenkomt op -0,5 laag.

D-1: Helling is erg flauw door grote lengte van garage, dit is een positief punt. Garage iets opschuiven richting laan 1914, staat nu erg dicht op keerwand D-gebouw. Tevens doorgang maken naar parkeerplaatsen bij bedrijfsrestaurant. Garage spiegelen over lengte as, inrit kan dan bij inrit garage D-gebouw komen en men komt op laag 0,5- de garage binnen. Onderste hellende lagen uitvoeren in klinkerbestrating op maaiveld. Trappenhuis verplaatsen naar hoek D-gebouw.

Architect zal gewenste aanpassingen verwerken.

Scoring en POP-model.

- Bereikbaarheid: Punt bevoorrading keuren wordt geschrapt, verder heeft draaien inrit variant B1 positieve invloed op bereikbaarheid. Tevens moet bij bereikbaarheid de routing in de garage worden beschouwd, zullen dit samen oppakken.
- [...] geeft aan dat TCO en initiële kosten zwaarder moeten wegen, zijn nu respectievelijk 15 en 5 %, dit moet samen 50% zijn.

Aangezien er verschillende wijzigingen aan de ontwerpen zijn doorgesproken zullen de scorengen veranderen, en hierdoor dus ook de uitslag van het POP-model veranderen. Afgesproken is dat de besproken wijzigingen worden verwerkt, en vervolgens de scoringen worden aangepast en verwerkt in het POP-model.

Actielijst en planning

Tijdens de Process Interface Management sessie (PIM) zijn gezamenlijk de actiepunten geformuleerd, en de afhankelijkheden bepaald. Vervolgens zijn aan de actiepunten deadlines gekoppeld, en hieruit volgt de planning. In bijlage 2 zijn de PIM-sessie, actiepunten, lijst en de planning toegevoegd.

Volgende vergadering

Dinsdag 27 oktober 14.00-16.00 uur te DHV Amersfoort, kamer volgt.
Bijlage 1: Documenten smartboard sessie
### Actielijst Parkeergarage Amersfoort

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<tr>
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<th>afgewend</th>
<th>Toevoeging</th>
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<td>17/09/2009</td>
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<tr>
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<td>30/09/2009</td>
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<td>Name of actor</td>
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<td>19/09/2009</td>
<td>Ondergrond zand, fundering op staal mogelijk, sonderingen volgen 40</td>
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<tr>
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<td>30/09/2009</td>
<td>CO2 eq gekoppeld aan materiaal gebruik</td>
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<td>25/09/2009</td>
<td>28/09/2009</td>
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</tr>
<tr>
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<td>30/09/2009</td>
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<tr>
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**Bereikbaarheid / verkeersveiligheid parkeergarage**

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<th>B1</th>
<th>C1</th>
<th>C2</th>
<th>D1</th>
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<td>-</td>
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<td>-</td>
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<td>+</td>
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<td>(let op bocht)</td>
<td>(let op bocht)</td>
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<td>-</td>
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**In/uit**:
- **Garage**: in
- **Omdraaiplaats**: uit
- **Parkeerplaatses restaurant**: in

**Huidig (referentie)**

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>B1</th>
<th>C1</th>
<th>C2</th>
<th>D1</th>
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<td>------------</td>
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<td></td>
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<td>Building spaces</td>
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**De project doelstellingen**

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**Organisatie**
Bijlage 2: PIM-sessie, actiepuntenlijst en planning
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## Actielijst Parkeergarage Amersfoort

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*For reasons of anonymity, names of actors have been replaced by "Name of actor"*
Appendix VII  Timeline diagram non-VDC
SYMBOLS

Engineering Meeting (EM)

Email interaction

ABBREVIATIONS

SE - Structural Engineering

INST - Installation Engineering (HVAC/MEP)
**ACTORS**

- **KvV**
  - Architect (KvV)
  - Project leader tunnel structure (Movares)
  - Project leader systems engineering (DHV)
  - Project leader installations (DHV)
  - Project leader installations (DHV)

- **Brede AAA**
  - Project leader transfer (Movares)
  - Project leader conditioning (Movares)
  - Project leader structures (DHV)
  - Lead structural engineer (DHV)

- **Advisor Urban Space** (DHV)

**TIMELINE**

- 26-11-2006: EM 1 (SE)
- 12-12-2006: EM 2 (SE)
- 9-1-2007: EM 3 (SE)
- 6-3-2007: EM 6 (SE/INST)
- 13-3-2007: EM 7 (SE)
- 20-3-2007: EM 8 (SE/INST)

**NSP Breda, FD phase (26-11-2006 until 30-3-2007)**
Appendix VIII Organization visualization: organization charts

Organogram Brede AAA

Organogram NSP Breda d.d. 13.10.2008

For reasons of anonymity, names of actors have been replaced by "Name of actor"
Appendix IX  non-VDC minutes
Betrek: OV terminal Breda
Onderwerp: 3e constructieoverleg brede AAA - KVV
Plaats: Architectenbureau Koen van Velsen
Aanwezig: Name of actor - Brede AAA
: Name of actor - Brede AAA
: Name of actor - Brede AAA
: Name of actor - Brede AAA
: Name of actor - Architectenbureau Koen van Velsen B.V. (KVV)
: Name of actor - Architectenbureau Koen van Velsen B.V. (KVV)
: Name of actor - Architectenbureau Koen van Velsen B.V. (KVV)

Verslag digitaal verzonden aan de aanwezigen en aan:
: Name of actor - Brede AAA
: Name of actor - NS vastgoed
: Name of actor - Prorail
: Name of actor - Brede AAA
: Name of actor - Brede AAA
: Name of actor - Brede AAA
: Name of actor - Brede AAA

N.B. cursieve tekst is actiepunt uit eerder constructieoverleg

ALGEMEEN

Doel van dit aparte constructieoverleg is het verduidelijken van de constructieve uitgangspunten door de brede AAA, evenals het verduidelijken van de architectonische uitgangspunten in relatie tot de constructie door KVV.

Aan de hand van de agenda worden constructieve aspecten per gebouwonderdeel besproken.

2.1 N.B. De inmetingen van de perrons en de spoortrajecten zijn inmiddels verricht.

Verstrekkingdatum tekeningen nog niet bekend.

AAA

DWG’s met de inmeetgegevens zijn ontvangen.

Op basis van bestaande plattegronden, die waarschijnlijk a.h.v luchtfoto’s zijn gemaakt zijn hoogtemetingen op tekening toegevoegd. Bestaande tunnel en trappen zijn ook horizontaal ingemeten.

De hoogten van de sporen en perrons verschillen onderling. Om de hoogten van de stijg punten gelijk te houden is plaatselijk een aanpassing nodig van het hoogteverloop van de één of meer sporen.

Een verdere uitwerking hiervan volgt volgens KVV in de bouwvoorbereidingsfase.

3.1 KVV wil een betrouwbare onderlegger van de bestaande situatie i.v.m. positionering nieuwbouw t.o.v. spoortraject.

AAA geeft aan dat de sporen zelf doorgaans wel goed op tekening staan en dat dit maatgevend is voor de positionering van de perronranden e.d. Staan de sporen goed op tekening?

Aparate bespreking beleggen i.v.m. positionering station in Rijksdriehoek.

DAK/HELLINGBAAN

2.4 - Brede AAA heeft conceptversie van kostenraming van de dakconstructie verstrekt.

Deze raming is onduidelijk, omdat geen vergelijk kan worden gemaakt met de
De raming moet qua systematiek in overeenstemming worden gebracht met die van HRC uit het VO. De kostenraming van de stationsdakconstructie roept nog steeds vraagteken op. Systematiek en gegevens sluiten nog niet aan op die van IGG. AAA past de raming komende week nogmaals aan.

2.6 60 min of 90 min brandwerendheid aanhouden?
Nog geen uitsluitse over 60 min of 90 min brandwerendheid hoofddraagconstructie stationsoverkapping/parkeerdek.
Bouwbesluit geeft volgens AAA geen uitsluitse.
Door toepassing fire engineering mogelijk hoofdconstructie 90 min brandwerend uit te voeren. KVV doet navraag bij brandveiligheidsadviseur (LBP)
Onderste 2,5 m kolommen Ø 450 mm bij 60 min WBDBO, Ø 500 mm bij 90 min WBDBO. Bruto maat inclusief RVS bekleding.

KVV streelt naar 60 min brandwerendheid i.v.m. slankere dimensionering kolommen. Ontwerpuitgangspunt voor AAA blijft vooral nog 90 min. brandwerendheid.

Buitenkant borstwering en plafonds hellingbanen ook bekleden met staalplaat i.v.m. naden een esthetisch beeld.
Vooral nog geen acoustische beplating toepassen. Alleen bij VTW mogelijk budget beschikbaar.
AAA onderzoekt mogelijk staalplaatbekleding als verloren bekisting toe te passen.

3.3 Onderzoeken welke bewerking tegen corrosie moet worden toegepast op staalplaat bekleding. Thermisch verzinken, galvaniseren, poedercoaten, mojfen etc.
KVV neemt hierover contact op met bouwfysisch adviseur (LBP)

2.7 De volgende varianten worden onderzocht op constructieve haalbaarheid en kosten:

1. Betonnen kolommen met stalen bekleding, waarvan de onderste 2,5 m in RVS i.c.m. beklede stalen vakwerkliggers.
2. Stalen kolommen, waarvan de onderste 2,5 m in RVS i.c.m. beklede stalen vakwerkliggers.
3. Betonnen kolommen met stalen bekleding, waarvan de onderste 2,5 m in RVS met betonnen liggers (momentvast verbonden)

De combinaties betonnen kolommen met betonnen liggers en betonnen kolommen met stalen vakwerkliggers zijn volgens de laatste raming AAA voor de zelfde kosten uit te voeren. De beide combinaties voorzien in hun eigen stabiliteit.
De kostenraming wordt nog wel verder bijgesteld. (zie punt 2.4)
Er is een overzichtstekening pre-DO verstrekt door AAA waarop ook de variant met stalen kolommen is meegenomen, maar die valt buiten de laatste raming.

2.8 Betonwand d=250 mm voldoet. Kolom als alternatief voor oplegging dakbalken t.p.v. aansluiting kantoorgevel i.p.v. betonwand onderzoeken.
Aanhouden.
Betonwanden woningen d=300mm

3.4 Bij keuze om kantoorgevel aan spoorzijde als ‘gesloten wand ’ uit te voeren minimale penantbreedte bepalen i.v.m. gevelbeeld. AAA onderzoekt dit.
Aandachtspunt: tijdelijke ondersteuning stationsoverkapping/parkeerdek bij bouw, wanneer kantoren niet gelijktijdig worden gebouwd.
2.9 Perronkolommen busterminal onderzoeken op aanrijdbeveiliging i.c.m. afstand tot perronrand. Aanhouden.

2.10 Vorming aansluiting prefab hellingbanen nog niet onderzocht i.c.m. stabiliteitsvraag. Borstweringen hellingbanen en kolommen d.m.v. ‘natte knopen’ aan elkaar verbinden. KVV stelt voor breedplaatvloer opleggen op hoeklijnen, aanstorten in druklaag. Verder uitwerken door AAA. Aanhouden. Zie ook punt 3.2

2.11 Afstand perronrand-kolommen controleren. (minimaal 2,5 m) . Hart spoor b.k. kolommen 3,5 m aangehouden in tekening. Aanhouden.

2.12 Kolommen parkeerdok komen vrij aan het spoor te staan aan de uiteinden van de treinperrons! Mogelijk duikbootconstructie toepassen? Duikbootconstructie voldoet niet. Oplasbaar d.m.v. zijgeleiding aan te brengen conform VO HRC. Afgehandeld.


2.14 I.v.m. aanrijdbeveiliging voorstel KVV om kolommen parkeerdak aan busbaan op betonwand van 600 mm hoog te plaatsen. Voldoet dit? Onduidelijk welke norm te hanteren. Voorlopig uitgangspunt kolommen aan busbaan gelijk kolommen op busperron individueel op aanrijding berekenen.

2.15 KVV geeft nogmaals aan dat de kolommenrij aan de noordzijde van de hellingbaan mogelijk zwaarder kan worden uitgevoerd, zodat deze bijdragen aan de stabiliteit van de dakconstructie. De overige kolommen die aan de hellingbanen verbonden zijn voorzien dan enkel en alleen in de ondersteuning van de hellingbanen. Doorsnijdingen van de liggers resulteert mogelijk in extra zware kolommen aan spoorzijde. KVV geeft aan dat getracht moet worden alle zwaardere kolommen in een rij te krijgen door horizontale krachten mogelijk om de daksparingen heen te leiden. Afgehandeld.

2.16 De brede AAA vraagt aan KVV een horizontale verbinding te mogen maken halverwege de sparing van de hellingbaan in het parkeerdok t.b.v. het afdragen van horizontaalkrachten. KVV geeft aan dat er mogelijk een lichte verbindingsslag voor voetgangers kan worden gecreëerd. KVV onderzoekt dit verder. Verbindingsslag uitvoeren als troglegger om vloerdikte te beperken. Borstweringen in mogelijk in beton uit te voeren. Afwerken met staalplaat bekleding?

2.17 Eindstreunen westzijde dak constructief nog niet opgelost. Aandachtspunt AAA. Uitkragende vloervelden ondersteund door vakwerk. Valt binnen volume verlaagd plafond. E.e.a. volgens pre-DO tekening AAA

2.18 Gevelkolommen aan Zuidplein mogelijk te verkleinen naar 650x400mm . Smalle zijde in aanzicht. Benodigde neto dimensies vlg opgave AAA 550mm x 500mm. KVV bestudeert dit.

HOV Busstation

2.19 KVV verstrekt tekening in vergadering met voorstel t.p.v. de entree van de hellingbanen 2 stramien te overspannen met bruggigers. AAA onderzoekt of dit mogelijk is. Voorkeur voor tussenondersteuning tussen in- en uitritstroken. Bruggigers sluiten
aan op vloerveld vijver. Eventuele balk over hellingbaan minimaliseren. Mogelijk aansluiting (kwart cirkel) als kolomschijfconstructie uitvoeren. (i.h.w.g.)

**Hoofdpassage/ Tunnel**

2.20 *Kritische toetsing diameter kolommen. KVV geeft aan kleinere diameter kolommen te willen vanuit ruimtelijke beleving tunnel. Aanhouden.* AAA

2.21 *Er bestaat een verschil in aanlegdiepte tussen de tekeningen van het VO van HRC en die van KVV van 150 mm volgens de brede AAA. KVV onderzoekt dit.* KVV

Aanlegdiepte b.k. tunnelvloer vlgs HRC 0.26m – N.A.P. Volgens tekeningen KVV 0.21m- N.A.P.

Hoogte en aantal optreden perronstijgpunten en aanlegdiepe tunnelvloer vlgs tekeningen KVV aanhouden.

Afgehandeld.

2.22 *De brede AAA legt het bovengenoemde verschil voor aan hun geoloog i.v.m grondwaterstanden.* AAA

*Conclusie: AAA verwacht geen problemen met grondwaterstand. Afgehandeld.*

2.23 *KVV past doorsneden aan over zuidhal i.v.m. gewijzigde kolomposities. Belastingberekening plantenbak aanhouden.* KVV/ AAA

Posities kolommen worden verder onderzocht om troglijker mogelijk te maken. Aangepaste dwarsdoorsneden verstrekken aan AAA.

2.24 *T.b.v. het ondersteunen van twee kolommen van de hellingbaan t.p.v. de aansluiting van de tunnel op de noordhal zijn twee balken door KVV op tekening aangegeven. AAA controleert of de afmetingen voldoen.* AAA

De balk t.p.v. de trap is berekend en voldoet volgens AAA. De andere balk moet nog uitgerekend worden.

2.25 *De horizontale stabiliteit van het steunpunt van de kolommen van de stationsoverkapping t.p.v. de stijgpunten van de treinperrons behoeft nog nader onderzoek.* AAA

Volgens pre-DO tekening betonnen uitkraging i.c.m. verdikking betonwand tot 650 mm. Mag maximaal 550mm zijn i.v.m. natuursteen afwerking. AAA past dimensionering aan.

**Vastgoed kantoren**

2.26 *Brede AAA legt nieuw constructief concept voor waarbij de constructie in zijn eigen stabiliteit voorziet door middel van momentvaste verbindingen tussen kolom en balk.* AAA

2 varianten:

1. tafel d.m.v. inklemming met portalen i.c.m. stabiliteitsverbanden t.p.v. patio’s
2. portalen met knooppuntversijvingen vanaf busperron. Geen stabiliteitsverbanden.

Vooral de problemen met overstekken lijken hiermee opgelost. De stabiliteitsverbanden uit variant 1 zitten wel hinderlijk in de weg m.b.t. de indeelbaarheid van de kantoren. KVV onderzoekt consequenties nieuw constructief concept. KVV

KVV geeft er de voorkeur aan de stabiliteit van de kantoren volledig uit verstijfde knopen halen.

AAA geeft aan de trappenhuizen voor de stabiliteit buiten beschouwing te houden. Afgehandeld.

2.27 *Brede AAA onderzoekt de verdere dimensionering van de twee varianten i.v.m. kolomdimensies busperron e.d.* AAA

Aanhouden

3.5 *KVV onderzoekt voorstel afwatering en pakketsamenstelling parkeerdek* KVV
Einde overleg

Volgende afspraak constructieoverleg ten kantore van KVV:
dinsdag 23 januari 2007 13.00uur

Genoteerd door [...] architectenbureau K. van Velsen d.d. 10 januari 2007.
Appendix X  Timeline diagram task conformance VDC
### SYMBOLS

- **Design Team Meeting (DTM)**

- **Email interaction**

- **Design task finished at the targeted deadline**

- **Design task not finished at the targeted deadline, but prior to the next meeting**

- **Design task not finished prior to the next meeting**

- **Design task status unknown**

### DESIGN TASKS

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<th>Task Description</th>
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<td>Status air duct</td>
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<td>Accessibility of project directory</td>
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<td>Input accessibility</td>
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<td>Scoring sustainability</td>
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<td>Change to parking place width 2.4 m</td>
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<td>Input costs</td>
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<td>Determine scoring</td>
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<td>Combine input in presentation</td>
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<td>32</td>
<td>Presentation for the board</td>
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</table>
Appendix XI  Timeline diagram task conformance non-VDC
**SYMBOLS**

- **Engineering Meeting (EM)**
- **Email interaction**
- **Green**: Design task finished prior to the next meeting
- **Red**: Design task not finished prior to the next meeting
- **Gray**: Design task status unknown

**DESIGN TASKS**

2.1 Measurement of platforms and tracks
2.2 Research retaining wall
2.3 *Not a task*
2.4 Change request for PoR
2.5 Adjustment of budget estimate
2.6 Research concrete beams
2.7 Structural feasibility of variants
2.8 Research support beams
2.9 Research collision protection
2.10 Research stability access ramp
2.11 Check distance columns
2.12 Research columns parking deck
2.13 Research lattice girder
2.14 Check feasibility of collision protection
2.15 Change column sizes
2.16 Research pedestrian bridge
2.17 Work out western side of roof
2.18 Reduce size of facade columns
2.19 Research span access ramp
2.20 Check size of columns travelers tunnel
2.21 Check drawings for different levels
2.22 Check groundwater level
2.23 Update architectural drawings
2.24 Check of dimensions of beams
2.25 Research horizontal stability

2.26 Research structural concept
2.27 Research into column dimensions
3.1 Check drawings/plan meeting
3.2 Research steel permanent casing
3.3 Research corrosion protection
3.4 Determination minimum pilaster width
3.5 Research drainage and roof composition