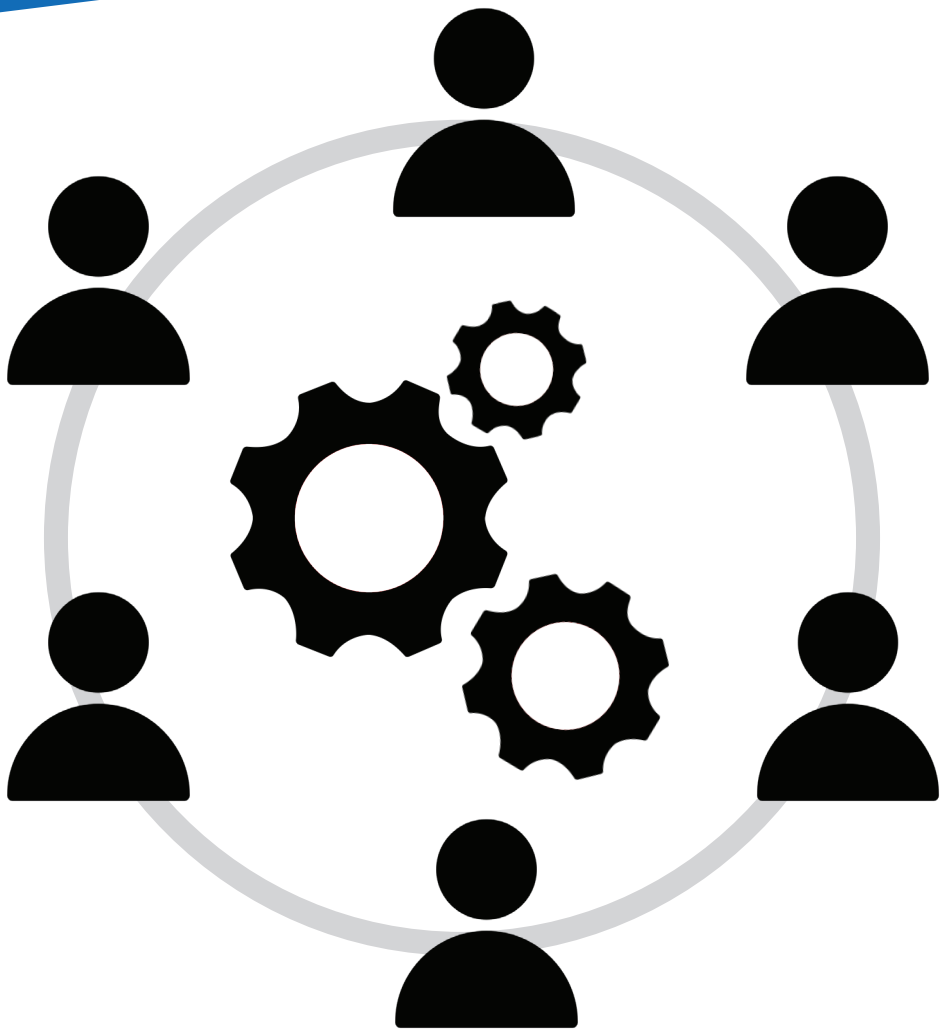
# A road map for constructive collaboration among stakeholders

*An improvement to stakeholder participation in Virtual Design and Construction engineering design projects*



TU Delft

Royal HaskoningDHV
*Enhancing Society Together*

# Master thesis

# A road map for constructive collaboration among stakeholders

*An improvement to stakeholder participation in Virtual Design and Construction engineering design projects.*

X.D. van Schie

August 2016

Construction Management and Engineering
at Delft University of Technology

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# Colophon

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# Preface

With the submission and approval of this report, I have completed my graduation thesis and fulfilled all requirements to obtain the Master degree for Construction Management and Engineering at the Facility of Civil Engineering and Geosciences. The last couple of months, in which this report has taken form, have been intense, educational, but most of all interesting.

With this research project I was able to work on the subject of project management which has intrigued me since the start of my Master's degree. Furthermore, it allowed me to experience an engineering firm up close. It helped develop my own perspective on the current state of the engineering industry and what the future might hold for the industry in the coming years. In my opinion the industry has some tough times ahead, but the future is still as bright as the sun.

This thesis however would not have been possible without the help, support, and knowledge of several others. Therefore, I would like to express gratitude to the following people:

First of all, I would like the thank the members of my graduation committee. Hans Bakker, for his critical perspective and his ability to place my research into a different light. Sander van Nederveen, for his input during the several brainstorm sessions we had. Bert Enserink, for his open-minded view on the project. Jeffrey Rampaart, who led me think outside of the box and put me in contact with interesting people. And Eric Delhez, for critically assessing the content and structure of my work during this period.

Furthermore, I would like to thank all employees of Royal HaskoningDHV for their open and kind attitude in which they have assisted me in any kind of way, during last couple of months.

Lastly, like most graduation projects, the process has been characterized by its ups and downs. Through good and bad periods my family, friends, and girlfriend have provided me with their unconditional support, feedback, confidence, and moments of relaxation to take my mind of things.

Xander van Schie
August 2016

# Summary

Currently we are living in a world that is rapidly changing. Although, this world provides us with many new opportunities such as the electric car, artificial intelligence, and virtual reality. It also causes existing ideas, industries, and societies, if they do not adapt or reinvented themselves, to disappear. Take for example the digital camera that has been the death sentence for the (previously) world famous Kodak company. Although the disappearing of the engineering industry is highly unlikely. The industry is experiencing difficulties while performing projects due to the increasing project complexity, growing amounts of information, and the fragmented nature of the industry.

These difficulties have led to the re-evaluation of the current project management approach. This paradigm shift can be best described in the words of Morris (2013); shifting the attention from the execution of projects to the management of projects. Upon this mind-set a group of scholars at the CIFE of the Stanford University have developed a framework consisting out of multi-disciplinary performance models to increase multi-party collaboration, reduce response latency between stakeholders, and manage an engineering design project effectively on the product to be built, organisation that performs the design, and the process that an organisation follows to perform the design. With, at its centre, the objective to improve the decision-making quality of a project and thereby to decrease costs and reduce lead time. This framework is named by the founders Kunz and Fischer (2012) as *Virtual Design and Construction (VDC)*.

With this framework a great start is made. However, the methodology is still only theoretical, although several scholars have developed methods to structure the decision-making process. They have all focused on the internal processes of VDC. This has left the run-up (i.e. preparation) to a VDC-process unstructured. Especially preparation is important because this is the moment in which stakeholders start to interact, exchange information, and start to collaborate. These elements combined can be seen as the key aspects for good decision-making. Therefore, this research is aimed at improving the decision-making process by developing constructive collaboration among stakeholders in the run-up to a VDC-process. Hence, the following research question: *"In what way can constructive collaboration be developed in the run-up to a Virtual Design and Construction engineering design project to improve the decision-making process?".*

In order to provide an answer to this question both literature and practice were studied. With the literature study a more thorough description of the VDC methodology was provided and four stepping stones for developing constructive collaboration were formulated; *identify, classify, engage, and collaborate.* Current practice was studied by means of a case study. This study has confirmed the need for a more structured approach and has highlighted several additional aspects which are important in preparing a VDC-process. By combining the results of the theoretical and practical study a road map for developing constructive collaboration among stakeholders in the run-up to a VDC-process was formulated.

However, after performing a validation, by means of a questionnaire distributed among 32 VDC-experts of RHDHV, it appeared that the road map could not provide a satisfactory answer to the question of *"Which stakeholders are relevant and to what extent are they required to be involved in the process?"*. In order to provide an answer to this question the process management approach of de Bruijn, ten Heuvelhof, and in 't Veld (2010) was assessed and compared with the initial version of the road map. With this comparison multiple opportunities for improvement were identified. By combining these opportunities for improvement with the initial road map a revisited version of the road map was developed. See page 66 for the road map.

With this revisited version of the road map stakeholders will be stimulated to interact with each other on both process and substance related issues prior to the decision-making process; develop a sense of ownership for the process; and make them familiar with the group dynamics in an early stage. These aspects will result a positive stimulant to participating stakeholders to pass the phases of Forming and Storming prior to the decision-making process. In the end, this will be beneficial to the actual VDC-process, because then the process can focus completely on the task for which it was developed; improving the quality of the decision-making.

Furthermore, due to the fact that the revisited version of the road map is visualised in a decision-tree like manner, the practical implication of the road map is large. Theoretically, VDC-experts could directly apply this road map when they are preparing for their next VDC-process. Besides this practical implication, the research has also made a contribution to the VDC body of knowledge by exploring and studying the run-up to a VDC-process. An area that had not yet been studied.

Lastly this research has shown once again that a unilateral project approach will not be sufficient to solve complex issues in our contemporary society and that (constructive) collaboration among people is key to achieve a higher decision-making quality. Put differently, constructive collaboration can be seen as the key to reducing the amount of project failures in our world, because in the end it is people who need people to perform complex projects. As Henry Ford once said: *"Coming together is a beginning; keeping together is progress; working together is success".*

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# Abbreviations

| | |
|---|---|
| Architectural, Engineering and Construction | AEC |
| Building Information Model | BIM |
| Centre for Integrated Facility Engineering | CIFE |
| Decision Breakdown Structure | DBS |
| Interactive Room | I-Room |
| Product, Organisation and Process | POP |
| Royal HaskoningDHV | RHDHV |
| Virtual Design and Construction | VDC |

# 1 Introduction

## 1.1 Research context

Every day new projects present themselves and are executed in the world of engineering. These projects can range from the development of a bridge for increasing the accessibility of an urban area to a long term road maintenance strategy for a province. However, if you would peel off the outer layer of appearance, context, size and complexity and look at the essence of just any project, its objective is to find a possible solution for a problem. In other words, a project is by definition a problem[1] solving process. (Ridder de, 2013, p. 12)

Although engineering firms have many decades of issue solving experience, it is getting more and more difficult for them to deliver projects within the provided budget and time and still achieve the requested level of performance. In other words, project failure in the terms of cost and time overruns is not an exception in the industry. (Flyvbjerg, Bruzelius, & Rothengatter, 2003)

**Project complexity**

One of the reasons for the existence of these project failures is the fact that projects are getting more and more complex. (Williams, 2002) To get a better understanding of the nature of project complexity researchers have conducted several studies. Baccarini (1996) defines in his research project complexity as *"consisting of many varied interrelated parts"* and discusses complexity by addressing it on the basis of two categories; organisational complexity and technological complexity. In addition, the paper of Bosch-Rekveldt, Jongkind, Mooi, Bakker, and Verbraeck (2011), in which they present a framework for characterizing project complexity in large engineering projects, shows that complexity can be divided into multiple categories. In their presented framework project complexity is measured on the basis of technical, organisational, and environmental elements. Even though project complexity is often described in one notion, it must be seen as a project characteristic which consists out of several interrelated categories.

**Growing amount of information**

In addition, due to advancing technology the amount of data available in the world continues to grow. The International Data Corporation, a global market provider of ICT market intelligence, predicts that the amount of data will be 44 times bigger in 2020 than it was in 2009. Translated into computer storage capacity this is 40 zettabytes, see figure 1. (Gantz & Reinsel, 2012) This growing and ever expanding amount of data is often described with the term 'Big Data'. To get a better understanding of the term 'Big Data' the definition of Gartner will be used: *"Big Data is high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision-making".* (Gartner,

[1] In this research the core of a project will be referred to as '*issue*' instead of '*problem*'.

2015) Data offers lots of potential value for projects, but only when it is translated into useful information and linked properly by involved actors into a project.

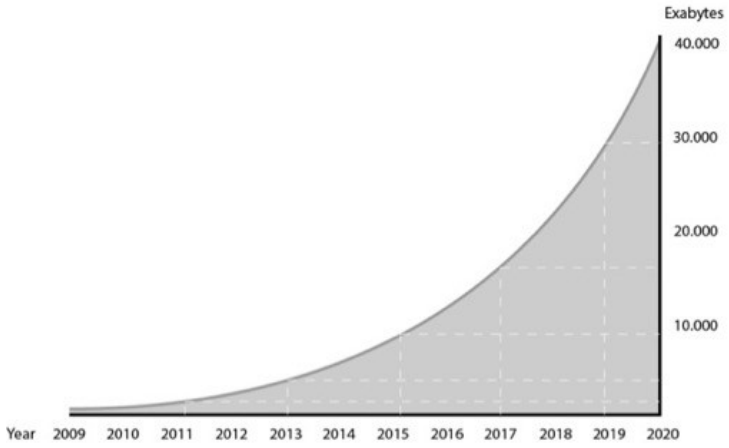


Figure 1: 50-fold growth from 2010 to 2020. (Gantz & Reinsel, 2012)

**Fragmented nature**

Lastly, the traditional project approach is characterized by a predictable linear process with a disciplined and deliberate planning, control methods, clearly defined project life cycle phases, and tasks which are performed in a sequential order without much changes. (Hass, 2007; Špundak, 2014) Due to these characteristics, disciplines and temporally involved parties work independently on their parts of the project and will collaborate only on an ad hoc basis. When operating independently, proper communication and information sharing is crucial in order to prevent miscommunication and misinterpretation of information. Nonetheless this is not always the case. As a result, the general tendency in the industry is that the traditional design process is rather fragmented leading to projects taking too long to be completed. (Baiden, Price, & Dainty, 2005; Kunz & Fischer, 2012)

## 1.2 Research gap

In the challenge to deal with this increasing complexity, information growth, and fragmented nature of the traditional project approach the industry is re-evaluating the approach. (Kunz & Fischer, 2012; Li, Lu, & Huang, 2009; Morris, 1994, 2013) One of the results of this re-evaluation is the change in the way the engineering industry approaches projects. In traditional project management, the focus was on the delivery of a product within the triple constraint, i.e. budget, time, and quality. (Hass, 2007) Nowadays the relationship between project management and people leadership is being more recognized, as Cooke-Davies (2002) stated *"…it is people who deliver projects, not processes and systems"*. This interconnection has resulted into an integral multi-disciplinary approach. (McManus & Cacioppe, 2011) The shift in approach can also be described by the ambition of Morris (2013), shifting the attention from the execution of projects to the management of projects.

**Virtual Design and Construction**

In this notion the methodology of Virtual Design and Construction (hereafter: VDC) is developed by researchers at the Centre for Integrated Facility Engineering (CIFE) of the Stanford University of California. (Kunz & Fischer, 2012) Put simply, the methodology of VDC can be seen as a different mind-set by which people approach a project. It combines a project's Product, Organisation, and Process in an integrated and dynamic manner – so to speak pressure cooker - with as objective to increase multi-party collaboration, reduce response latency between stakeholders, and optimize the Architectural, Engineering and Construction (AEC) process in terms of budget, time, and quality. (Kunz & Fischer, 2012) However, the VDC methodology is still undergoing theoretical development and therefore it does not present a set of formal processes and methods to structure the VDC-process. (Kam, 2005; Kunz & Fischer, 2012)

One of the effects according to Kam (2005, p. 239) is that *"although VDC concur in decision-making objectives, it does not provide a representation, methodology, and process for AEC decision information management to achieve good decision basis and consequently good decision quality"*. Especially decision-making is a very important aspect in the AEC industry, because the people working for AEC organisations are the ones who guide their clients to make informed decisions to strategically allocate their resources in a project.

In reaction to the absence of formal process and methods the POP (Kunz & Fischer, 2012), Narrative (Haymaker, Fischer, Kunz, & Suter, 2003), and Decision Dashboard (Kam, 2005) methodology were developed. In short, the POP methodology is a static representation of information shared among disciplines and models with the objective to assure consistency between function, form and behaviour of each of the Product, Organisation, and Process models. The narrative is a methodology that constructs, manages and controls project information with its dependencies in a formal and visual manner and the Decision Dashboard methodology allows project teams to interactively change, evaluate and document design decisions and make it possible to communicate and share these design decisions with other stakeholders. However, comparing the three methodologies, see appendix A, shows that despite structuring the information management and decision making process within a VDC-project all methodologies are based on an ideal situation in which all information is readily available and competent decision makers are present. Hence, the input of a VDC-project process (i.e. run-up to a VDC-process) remains unstructured with these methodologies. Something that has also been acknowledged by J. Kunz, one of the founders of the VDC-methodology. (personal communication, May 5, 2016).

**Informed decisions**

One of the key aspects of decision-making is information. (Howard, 1988) The more information is gathered, the more one is possible to make an informed and effective decision. (Howard, 1988; PMI, 2015) However, in the beginning of a project still little is known and proper information to allow good decision quality is relatively scarce. (Ridder de, 2013) Although more and more information will be available when a project progresses over time, postponing decision-making is also not the solution. This because when a project progresses over time, the influence of

stakeholders[2] on the design process decreases. Meaning that decisions that are already made earlier in the process exclude alternative design possibilities. (PMI, 2004) If design changes are still executed in a later stage, additional costs will be made to be able to implement these changes in the current situation. Furthermore, it will get increasingly more expensive to revisit decisions by stakeholders and allow changes in the design to be made. This relation between the ability to change, i.e. influence of stakeholders on the project process, and the cost of changes is shown in figure 2.

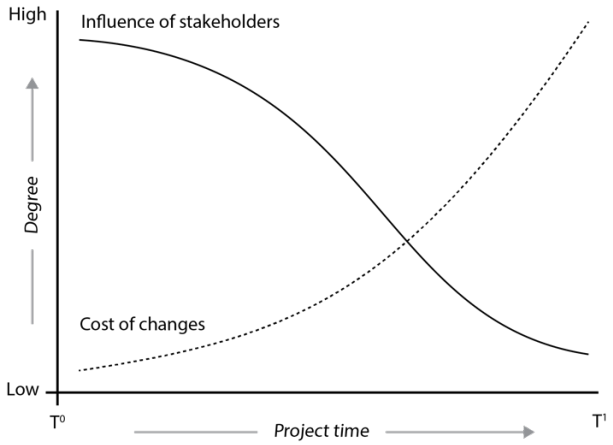


Figure 2: Relationship between stakeholder influence versus cost of changes over project time.

**Stakeholders and collaboration in decision-making**

Besides this need for information, there is also the requirement of having stakeholders with the right skills and experience available for decision making during a project. (PMI, 2015) Without it decisions can either not be made or are of lesser quality affecting the project outcome. Furthermore, due to the fact that AEC industry by nature is multi-disciplinary and requires the involvement and input of many different stakeholders, collaboration between them during decision-making is needed in order to achieve a successful project outcome. (Jung, Jeong, & Mills, 2014) Therefore collaboration can be seen as the binding element between stakeholders, information, and decision-making.

However, collaborating effectively[3] in a team with stakeholders is easier said than done. Before effective team collaboration is achieved a team will first have to go through several stages. In the widely acknowledged work of Tuckman (1965) these four stage are defined as forming, storming, norming, and performing (see figure 3). During the stage of *forming* members will start to interact with each other and discover opportunities and challenges. The stage is however still characterized by an independent character of team members. In the *storming* phase team members are trying to claim their position in the team by expressing their opinion. Due to this

[2] A Stakeholders is *"any group or individual who can affect or is affected by achievement of the organisations objectives"* (Freeman, 1984, p. 46)

[3] Effective collaboration will be referred to as constructive collaboration in this research.

intragroup conflicts are very common. Hereafter, during *norming* the team shares a common goal and is aware of the team dynamics. From this point on the rules and method for collaboration are determined and effectiveness of the collaboration in the team starts to increase. Lastly, during the *performing* stage the team works in harmony on a common goal and starts to turn into an issue solving entity.

Putting this back into the context of a project in which VDC is applied it would be desired to have a team that already passed the stage of forming and storming before entering such a pressure cooker. This due to the fact that VDC is all focussed on improving the effectiveness and efficiency of the decision making it the AEC industry. (Haymaker et al., 2005; Kam, 2005; Kam & Fischer, 2004; Kunz & Fischer, 2012)

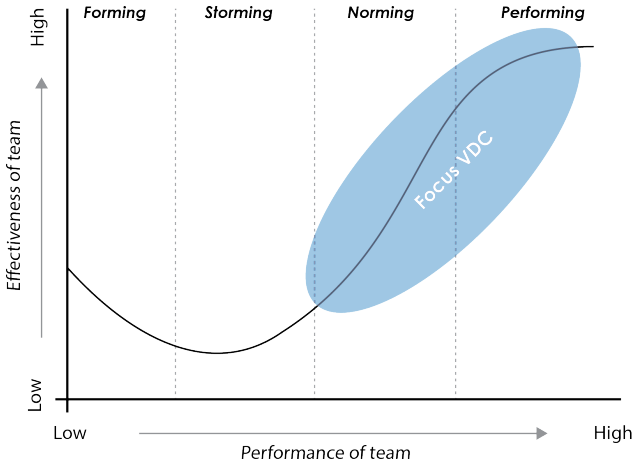


Figure 3: Tuckman's stages of group development. Edited.

**Room for improvement**

In short collaboration can be seen as the binding element between stakeholders and information in the decision-making of a project. See figure 4. In a traditional project these aspects already play an important role however when VDC will be applied this is increasingly more important. So, it would be desirable to have passed the forming and storming phase of a project team prior to the start of a VDC-process. However, currently there is no structured approach in order to develop constructive collaboration among stakeholders in the run-up to a VDC-project. Hence, there is room for improvement to the decision-making of a VDC-project.

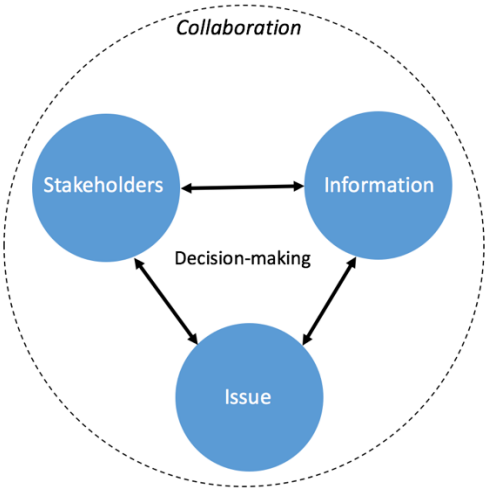


Figure 4: Schematic visualisation of interrelation between stakeholder, information, issue, and collaboration.

## 1.3 Research objective

The objective of this research is to create a road map to develop constructive collaboration among stakeholders in the run-up to a VDC-process. This will enable better decision-making during a VDC engineering design project.

## 1.4 Research questions

In order to achieve the previously described research objective, the following main research question is formulated.

MRQ: *In what way can constructive collaboration be developed in the run-up to a Virtual Design and Construction engineering design project to improve the decision-making process?*

However, to provide a well structured answer to the main research question this research will be supported by three sub-research question, which are presented below.

Theory

Before an improvement can be made to the Virtual Design and Construction methodology additional knowledge about the core of the methodology is required.

RQ1: *In what way does Virtual Design and Construction address the issues in the Engineering industry?*

After this literature will be studied to understand which elements are required to create constructive collaboration among stakeholders.

RQ2: *What elements are required for developing constructive collaboration among stakeholders?*

Practice

Lastly, due to the fact this research is conducted on an issue with roots in the practical application of VDC the current application of VDC by an engineering organisation will be observed.

RQ3: *How is the Virtual Design and Construction applied by Royal HaskoningDHV in its engineering design projects?*

## 1.5 Research design

In figure 5 the overall design for this research is shown. As can be seen in the figure both literature and practice will be studied. The literature study (chapter 2 & 3) will be focussed on the subjects of VDC, stakeholder identification, stakeholder classification, stakeholder engagement, and aspects of collaboration. The case study (chapter 5) on the other hand is focussed on the current application of VDC by an engineering organisation. On the basis of the results of these chapters a road map will be developed (chapter 6). To validate the road map, it will be tested by means of a questionnaire (chapter 7). The results of this questionnaire will be discussed (chapter 8) and used to make a revisited version of the road map (chapter 9). Lastly, an answer to the main research questions will be given in the form of a conclusion (chapter 10).

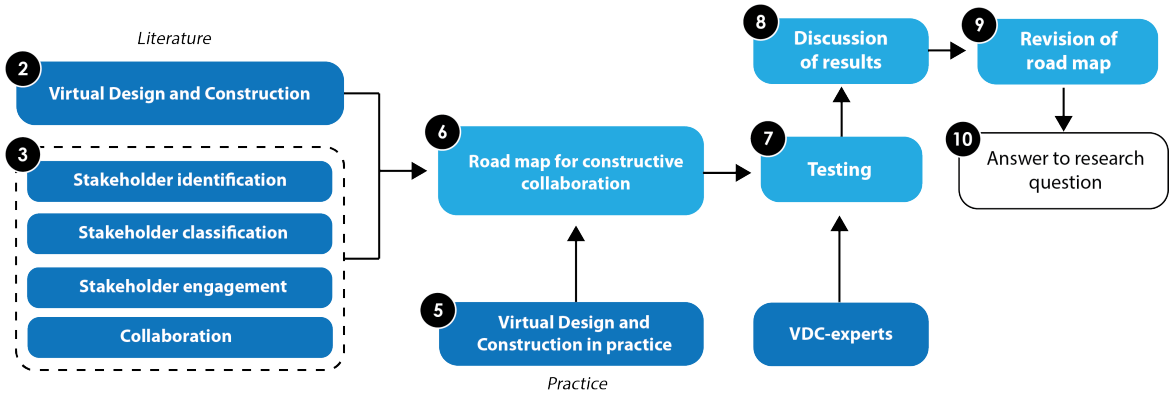


Figure 5: Research design (numbers are related to chapters).

## 1.6 Research scope

The scope of this research is demarcated by three components: Virtual Design and Construction, engineering organisations, and the engineering design process. Below the three elements will be briefly elaborated.

### 1.6.1 Virtual Design and Construction

The research is focussed on engineering projects to which the methodology of VDC is applied. As mentioned earlier the methodology is developed by Kunz and Fischer (2012) at the Centre for Integrated Facility Engineering (CIFE) at the Stanford University. A more detailed description of the methodology can be found in chapter 2.

### 1.6.2 Engineering organisation

In most cases when a company, organisation, or any other party (i.e. client) wants to undertake an engineering related project and it does not have the required in-house knowledge they will consult an engineering organisation to support them. Such an engineering organisation typically consists out of a group of engineers who work on project base to assist their client with making decisions with regard to the allocation of their resources in the design and engineering of a construction project.

### 1.6.3 Run-up of a VDC-process

The run-up to a VDC-process can also be referred to as the preparation of the VDC-process. During the preparation competent stakeholders are engaged to join the decision-making process, information regards the issue(s) at hand is gathered, and the VDC-session it-self is prepared by the VDC-facilitator and the project team.

## 1.7 Research relevance

The research presented in this report is both scientific and practical relevant.

### 1.7.1 Scientific

This research contributes to the body of knowledge of VDC. First by reason of that this research provides an in-depth assessment on how an engineering organisation has adopted the VDC methodology, applies VDC in engineering projects, and identifies issues which are encountered while using VDC in engineering projects. Second, it contributes to filling the theoretical gap in the VDC methodology by presenting a set of guidelines in the form of a road map to structure the run-up to a VDC-process. Lastly, this research in contrary to existing literature on VDC has put the focus on examining the preparation a VDC-process instead of solely focussing on the internal process in a VDC-process.

### 1.7.2 Practical

By reason that the road map presented in this research is developed in a practical context the practical implications are large. With the road map VDC-experts are presented with a set of guidelines to structure the run-up to a VDC-process and support them to develop constructive collaboration among stakeholders in the run-up and thereby improve decision-making in a VDC-process.

# 2 The Virtual Design and Construction methodology

In this chapter, the methodology of Virtual Design and Construction will be further elaborated. It must be noticed that although this research is focussed on the run-up to a VDC-process this chapter will provide a more comprehensive explanation of the methodology. The reason for this is that it will assist the reader to place the research into context. The elaboration will be guided by the following question.

RQ1: *In what way does Virtual Design and Construction address the problems in the Engineering industry?*

As already mentioned in the research context, VDC is developed by researchers at the CIFE at Stanford University in a response to the increasing complexity, information growth, and fragmented nature of the traditional project approach. Kunz and Fischer (2012, p. 1), researchers of CIFE at Stanford University and founders of the methodology, define VDC as follows: "*the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives"*. But for the purpose of this research a more specific description of VDC will be used. VDC is a framework consisting out of multi-disciplinary performance models to increase multi-party collaboration, reduce response latency between stakeholders, and manage an engineering design project effectively on the product to be built, organisation that performs the design, and the process that an organisation follows to perform the design. (Kunz & Fischer, 2012)

## 2.1 Elements of Virtual Design and Construction

The VDC framework consist out of four elements; POP modelling, Models are virtual, Metrics, and Integrated Concurrent Engineering. Each of the elements will be explained in the subsequent paragraphs (4.1.1.1 – 4.1.1.4).

### 2.1.1 POP Modelling

In order to stimulate collaboration and synergy between different stakeholders and disciplines, the VDC methodology uses the integrated perspective of the Product, Organisation, and Process (POP) methodology. The POP methodology is developed by Londoño, Cleetus, and Reddy (1991) and is based on the statement that a project manager can manage and control a project based on three aspects; the *Product* to be built; the *Organisation* that performs the design; and the *Process* that the organisation follows to create the design for the product. (Kunz & Fischer, 2012) The POP methodology enables stakeholders to build models of a project's Product, Organisation, and Product at an early state in the project, before any large commitment of money or time is made by the stakeholders. (Khanzode, Fischer, Reed, & Ballard, 2006)

In its most basic application, the POP methodology produces a POP model in the form of a spreadsheet, see table 1, on its axis; function, scope, and behaviour and; product, organisation, and process are displayed. The second column represents the functional intent of a project. This can be measurable objectives, such as space. The form and scope, or in other words design choices made, (column 3) are a response to the functional intent. It represents the things that are specified, designed or build by a project team. In the last column, the predicted or measured behaviour of a project element is shown. In the rows starting at two, the product elements of a project are shown. In the fifth row, the organisation that designs, builds, or operates the project is displayed and in row eight the process that an organisation follows during the project is given.(Kunz & Fischer, 2012)

| | **Function:** Objectives | **Form/Scope**: Design choices | **Behaviour**: Predictions |
|---|---|---|---|
| **Product** | | | |
| | Spaces, Elements, and Systems | Designed spaced, elements, and systems | Predicted costs ($) |
| | Measurable Objectives | Values | Predictions; Assessed values |
| **Organisation** | | | |
| | Actors | Selected actors | Predicted costs (hours or $) |
| | Measurable objectives | Values | Predictions; Assessed values |
| **Process** | | | |
| | Task | Designed task | Predicted cost (days or $) |
| | Measurable objectives | Values | Predictions; Assessed values |

Table 1: Overall content of a generic POP-model. (Kunz & Fischer, 2012, p. 11)

### 2.1.2 Models are virtual

The current paper document based project approach does not stimulate integration among different stakeholders and slight modifications in the paper documents can take up to hours to complete. In addition, each stakeholder has its own vocabulary, due to different disciplines or origin, which makes it difficult for stakeholders to provide proper comments on the two dimensional paper documents. (Kunz & Fischer, 2012)

The VDC methodology is created to stimulate integration and collaboration in a multi-party setting. Therefore, VDC POP models are made virtual, interactive, flexible and most of the time computer-based. This allows stakeholders with different languages in a multi-party setting to quickly explain, share, and change information during a session. (Kunz & Fischer, 2012) In order words, making VDC models visual and interactive reduces noise in the information.

In practise, the visualisation of the *product* often results in the application of a so called Building Information Model (BIM). A BIM can be defined as *"a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward."* (Smith & Edgar, 2008) However, a common misconception is that a BIM is

seen as a full representation of the framework presented by the VDC methodology. This is actually not the case, because a BIM is normally only focussed on the representation of the form and scope of the product, see table 1, and it does not model the rest of the VDC spectrum.

Figure 6: Example of a BIM project. (C&S Engineering and Designing Group, 2016)

In the visualisation of the *organisation* all stakeholders involved in the design and construction process are visualised in a model. (Kunz & Fischer, 2012) Among others, these stakeholders can be the client, architect, engineer, and other decision-makers. In addition, it is also important that stakeholders are linked to their responsibilities and tasks. This results in an organisational visualisation in the form of a network chart including all stakeholders and their responsibilities.

The visualisation of the *process* represents the design and construction process that the organisation follows during a project. (Kunz & Fischer, 2012) This process is often visualised in a network diagram which contains information on activities, tasks, interdependencies, and deadlines. It must be noticed that due to these aspects, the *process* is closely related to the *organisation*. By combining both *process* and *organisation* relationships can be established and made explicit. (Fischer, 2000; Kunz & Fischer, 2012)

Figure 7: A project team is visually mapping the organisation and process.(Fischer, 2000)

### 2.1.3 Metrics

In addition to visualizing the project's Product, Organisation, and Process, the VDC methodology prescribes the use of metrics. Metrics are the translation of project requirements and objectives

into measurable goals. (Kunz & Fischer, 2012) By consistently measuring these goals, the performance of a project's Product, Organisation, and Process can be measured and future performance can be predicted. This information is valuable, because it allows stakeholders to assess the current state of the project and steer the project towards the desired outcome. Similar to the visualisation of the Product, Organisation, and Process, the metrics are also categorized into these three groups.

### 2.1.4 Integrated Concurrent Engineering

The methodology of Virtual Design and Engineering brings stakeholders together in a multi-party collaboration. However, it does not prescribe how a team can work closely and effectively together during a design process. Integrated Concurrent Engineering supports VDC in this and is therefore an important component of the methodology. During the earlier years, Integrated Concurrent Engineering was also known as 'Extreme Collaboration'. (Garcia, Kunz, Ekstrom, & Kiviniemi, 2003; Mark, 2002)

Integrated Concurrent Engineering is a design method which is developed by TeamX of NASA in their Jet Propulsion Laboratory (JPL). With this method, TeamX managed to shorten the design process from a year to only a few weeks and reduced the variable costs to one third of what they previously needed at the JPL by using a traditional parallel design method. (Chachere, Kunz, & Levitt, 2004) Stanford University's CIFE researchers Chachere et al. (2004, p. 1) have studied ICE extensively and define Integrated Concurrent Engineering (ICE) as *"a singularly rapid combination of expert designers; advanced modelling, visualization and analysis tools; a set of consistent social processes, and a specialized design facility; to create preliminary designs for complex systems".*

A key feature of ICE is that stakeholders work in a so-called 'war-room' or in the case of VDC an Interactive Room (I-Room). An I-Room is characterized by the deployment of information technologies and co-location of stakeholders. This has as a twofold objective; first to maximise the communication and second to increase the information flow. (Garcia et al., 2003) An I-Room usually consists of three large touch sensitive screens, each showing projections of a computer which is linked to a shared network to allow information exchange. (Kunz & Fischer, 2012) In figure 8 an example of a I-Room can be found.

Figure 8: I-Room at Royal HaskoningDHV

The result of working with ICE in combination with an I-Room is that the response latency is reduced significantly. With response latency is meant the time between a question sent by a

stakeholder and receiving an answer to that question by an another stakeholder. In a traditional design process, this usually takes up to several hours or sometimes even days. (Kunz & Fischer, 2012)

## 2.2 VDC Maturity Levels

In the process of adopting the VDC methodology by an organisation, Stanford University recognizes three distinct phases; Visualisation and Metrics, Integration, and Automation. In order to make the transition from a traditional design process towards and VDC approach, organisations normally proceed sequentially through these steps. As a result, these steps are referred to by Kunz and Fischer (2012) as different VDC maturity levels.

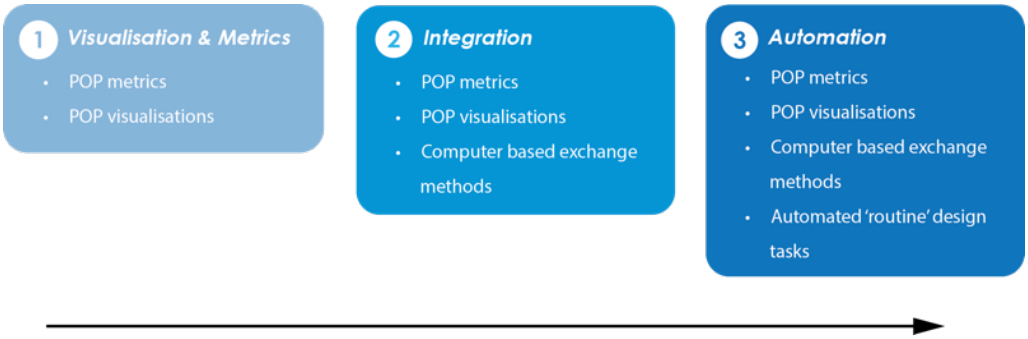


Figure 9: VDC Maturity levels. (Kunz & Fischer, 2012)

### 2.2.1 Phase 1 - Visualisation and Metrics

The first maturity level or phase is reached when design teams develop models for the product to be created, organisation that performs the design, and processes followed by the involved parties during the project. In addition, metrics are applied to measure and track the overall process and performance. The information necessary to create these models is gained from the involved parties. In this multi-party collaboration, it is important that there is sufficient knowledge and understanding of the models and an incentive to share information. (Kunz & Fischer, 2012) Without these elements it will be difficult to create complete models.

### 2.2.2 Phase 2 - Integration

In the second phase, integration of the POP models takes place. This integration is computer-based and allows modelling and analysis applications to exchange information easily. However, in order to achieve this integration of models and make information exchange possible, a common exchange standard is required. (Kunz & Fischer, 2012) Similar to the first phase, an incentive is necessary to encourage information sharing in this multi-party collaboration setting.

### 2.2.3 Phase 3 - Automation

The third and last phase uses automated methods to perform routine design tasks during projects. Routine tasks are activities that require less attention from the design team.

Automating these task increases the design efficiency and effectiveness, and decreases project duration. (Kunz & Fischer, 2012)

## 2.3 Applicability of VDC in projects

Due to the fact that VDC methodology focusses on improving the Product, Organisation, and Process of a project with the aid of integrated multi-disciplinary performance models, it does not focus on a specific project phase. (Kunz & Fischer, 2012) Hence, the VDC methodology is suitable to be applied throughout all phases of a project.

## 2.4 Limitations of VDC

Although VDC enables better project management by integrating Product, Organisation, and Process, the methodology also has limitations. One of them is that the theoretical base of the VDC methodology is still being further developed. (Haymaker et al., 2005; Kam, 2005; Kunz & Fischer, 2012) Due to this continuously changing theoretical base, the current practise of VDC lacks formal methodologies to manage and communicate information and processes between different stakeholders in a project resulting in a less effective, efficient, accurate, and fluent decision making process. (Haymaker et al., 2005; Haymaker & Sutter, 2006)

## 2.5 Conclusion

After reviewing the literature, it can be concluded that the VDC methodology presents a framework consisting out of four elements; POP modelling, Virtual Models, Metrics, and Integrated Concurrent Engineering. With this framework, an engineering organisation should be able to increase multi-party collaboration, reduce response latency between stakeholders, and manage a construction design project effectively on the product to be built, organisation that performs the design, and the process that an organisation follows to perform the design. In addition, the application of VDC at an engineering organisation can be categorized into three levels; Visualisation and Metrics, Integration, and Automation. The different levels represent the degree to which the VDC methodology integrates the P, O, and P with computer-based technologies.

However, despite the fact that the VDC methodology covers the problems faced by the engineering industry and is suitable for use in all phases of an engineering design project, it also has a major limitation. The methodology is still undergoing theoretical development. As a result, VDC lacks a complete theoretical foundation causing an absence of formal processes and methods to structure the VDC-project process.

# 3 Stepping stones for constructive collaboration

Before constructive collaboration can be created, several essential questions need to be answered. What is a stakeholder? What activities should be undertaken to identify and determine who to involve or not? How are stakeholders engaged in a project process? And, in what way can stakeholders successfully collaborate? By answering these questions, stepping stones are identified that act as building blocks for developing constructive collaboration.

In this chapter, the elements required for developing constructive collaboration will be defined. This process will be guided by the following question.

RQ2: *What elements are required for developing constructive collaboration among stakeholders in projects?*

## 3.1 What is a stakeholder?

In the introduction of this research, the widely acknowledged definition of Freeman (1984) for the notion '*stakeholder*' was presented. However, due to the fact this still presents a very broad view of what a stakeholder can be, a narrower definition is needed for this research.

PMI (2014, p. 23) defines stakeholders as: "*persons or organisations, who are actively involved in the project or whose interest may be positively or negatively affected by the performance or completion of the project*". When compared with the definition of Freeman, the two show many similarities. However, the points on which the definition of PMI (2014) distinguishes itself from the definition of Freeman is that it has put the focus on a project context and has included the attitude of a stakeholder regarding a project. On the other hand, L. Bourne (2005) has explicitly used the definition of Freeman (1984) to construct a narrower definition applicable to the context of projects. By combining the definition of PMI (2004) for a Project; *"A temporary endeavour undertaken to create a unique, service, or results"* with the definition for a stakeholder of Freeman (1984) the following definition has been constructed: *"Stakeholders are individuals or groups who have an interest or some aspect of rights or ownership in the project, can contribute in the form of knowledge or support, or can impact or be impacted by the project".* (L. Bourne, 2005, p. 43) In the definition of Bourne, two distinctive aspects can be noticed when comparing it with the other two definitions. The first distinctive aspect is the addition of the type of relationship between a stakeholder and a project and the second distinctive aspect is in what way stakeholders can contribute to the project. However, this research will adopt the definition of Eskerod and L. (2013), because their definition puts the focus on the project process and project outcome that is in line with the scope of this research (i.e. VDC engineering projects). Their definition for stakeholders is as follows: "*Stakeholders are individuals or entities*

*represented by individuals who can affect or who can be affected by the project process or project outcomes".* (Eskerod & L., 2013, p. 3) Table 2 provides an enumerated overview of the previously presented definitions.

| Definition | Author |
|---|---|
| Wide focus | |
| *A stakeholder is any group or individual who can affect or is affected by achievement of the organisations objectives.* | *(Freeman, 1984, p. 46)* |
| Project focus | |
| *Stakeholders are persons or organisations, who are actively involved in the project or whose interest may be positively or negatively affected by the performance or completion of the project.* | *(PMI, 2014, p. 23)* |
| *Stakeholders are individuals or groups who have an interest or some aspect of rights or ownership in the project, can contribute in the form of knowledge or support, or can impact or be impacted by the project.* | *(L. Bourne, 2005, p. 31)* |
| *Stakeholders are individuals or entities represented by individuals who can affect or who can be affected by the project process or project outcomes.* | *(Eskerod & L., 2013, p. 3)* |

Table 2: Stakeholder definitions.

## 3.2 Finding stakeholders

In order to identify stakeholders, the question of "Who are they?" must be asked. (Frooman, 1999, p. 1) In the literature, the identification of stakeholders is closely related to the analysis of stakeholders. (Achterkamp & Vos, 2007; L. Bourne, 2005; Bryson, 2004; Eden & Ackermann, 1998; Mitchell, Agle, & Wood, 1997; Olander, 2003) The following section will focus on the identification of stakeholders. The analysis (i.e. classification) of stakeholders will be discussed in the next paragraph.

At the start of a stakeholder identification endeavour, there is an certain topic[4] at hand which relates stakeholders in one way or another. (Eden & Ackermann, 1998) On the basis of such an issue, the majority of stakeholder identification methodologies will conduct a brainstorm session. (Bryson, 2004) These brainstorm sessions are held either individually followed by sharing the results with a group or are held in one large or several smaller groups. The question of whom to include, how, and why during this identification is always difficult. (Bryson, 2004) But, generally if a party has information to contribute what makes the list of identified stakeholders more comprehensive they should be included and when their involvement is impractical or unnecessary they should not. (Thomas, 1995)

In these brainstorm sessions the participants search for potential or actual relations between stakeholders regarding the issue at hand (i.e. project). (Achterkamp & Vos, 2007; L. Bourne, 2005; Bryson, 2004; Mitchell et al., 1997) In the widely acknowledged research of Mitchell et al.

[4] In this research a topic in context of stakeholder identification is referred to as issue.

(1997) these types of relations were labelled as *Power*, *Legitimacy*, and *Urgency*. The *Power* of a stakeholder can be seen as the ability of a stakeholder to influence others to do something what otherwise would not have been done. Legitimacy refers to the extent actions of a stakeholders are desirable within the perspective of a social construct. (Suchman, 1995) Lastly, *Urgency* refers to the extent to which a stakeholder can claim for action regarding the issue. (Mitchell et al., 1997) The result of such a stakeholder identification endeavour can either be a list with stakeholders or a diagram visualizing the stakeholders and their relation to the issue. (Bryson, 2004)

In short, finding stakeholders (i.e. identifying) is all about answering the questions of *whom* and *why* to involve the different stakeholders. This process of stakeholder identification will be conducted in the form of an individual or group brainstorm session that is built around an issue. In this brainstorm session, participants try to identify as many stakeholders as possible on the basis of their knowledge of the issue at hand resulting in an overview of stakeholders regarding an issue or project.

## 3.3 How to classify stakeholders?

A project often involves a wide variety of stakeholders ranging from client and investors all the way up to green groups and local communities. (Chinyio & Olomolaiye, 2009) However, after defining what a stakeholder is and how to identify them it still appears that all stakeholders are equally important. This is often not the case. Therefore, a further classification of the different stakeholders is needed to be able to say something useful about the different stakeholders regarding a project.

One manner to classify stakeholders on a high level is to group them by making a division between internal and external stakeholders. (Winch & Bonke, 2002) Internal stakeholders can be defined as members of the project team or people who provide finance. External stakeholders can be defined as those who are affected by the project in one way or another. (Winch & Bonke, 2002) A second more detailed manner is to place them in a Power versus Interest matrix. Typically, a Power versus Interest matrix will be deployed to determine which players' interests and power must be taken into account in order to challenge the issue at hand. In addition, it is also useful to discover potential coalitions between stakeholders, what behaviour should be nurtured and whose involvement must be sought, and lastly it provides valuable information on how to convince stakeholders to adjust their opinion. (Bryson, 2004) As can been seen in figure 10, a Power versus Interest matrix consists out of a two-by-two grid where the dimensions on the axis are the interest and power of a stakeholder regarding the issue.. Four categories of stakeholders can be identified: subjects, players, crowd, and context setters. (Eden & Ackermann, 1998) *Subjects* are stakeholders with a high interest and a low power; *Players* have a high interest and power, *Crowd* have a low interest and power, and *Context setters* are the ones with a low interest but a high power.

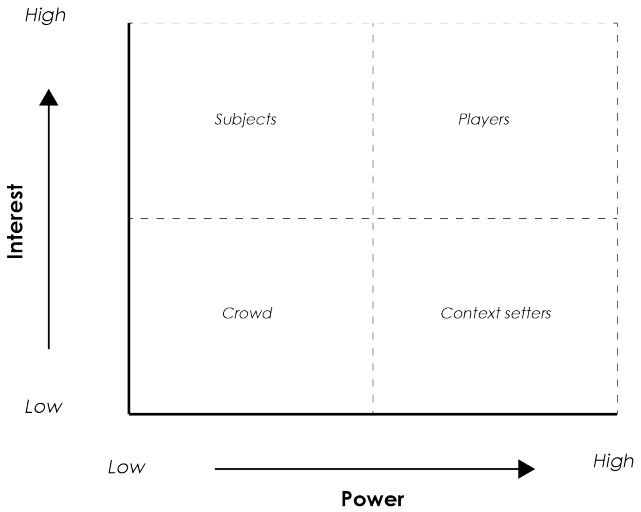


Figure 10: Power versus Interest grid. (Eden & Ackermann, 1998, p. 122)

The Power versus Interest grid provides a more detailed and visual representation method of classifying stakeholders, but is not primarily focussed on the context of engineering projects. In addition, it still does not provide a clear answer to the boundary drawing question of who to or who not to involve.

A scholar who has incorporated this boundary drawing issue in the classification of stakeholders is Ulrich (1983). On a high level, Ulrich defines two basic groups of stakeholders: the involved and the affected. This is in essence similar to the classification of Winch and Bonke (2002); an involved is an internal stakeholder and an affected is an external stakeholder. In order to belong to the involved, someone needs to have some kind of contributing resource to an organisation (e.g. expertise or financial). For the latter, someone should actually or potentially be affected by the outcome of the system. (Achterkamp & Vos, 2007)

In the group of the involved, three roles are distinguished by Ulrich (1983). These roles are based on the sources of influence an involved can have. The first is the source of motivation. This leads to the role of the *client* (i.e. whose objectives are being served). Second is the source of control and leads to the role of the *decision maker* (i.e. the one who has the power to decide). Lastly, the third is the source of expertise leads to the role of the *planner* (i.e. the one who contributes the required knowledge). The second basic group, the affected, according to Ulrich (1983) is a difficult matter to identify completely. Therefore, the affected can only be bounded by means of representation. Meaning some individual or party will represent others. In addition, this representation can only be determined by those who will represent them. Ulrich names this role the *witness.* See figure 11 for a detailed overview of the groups and roles.

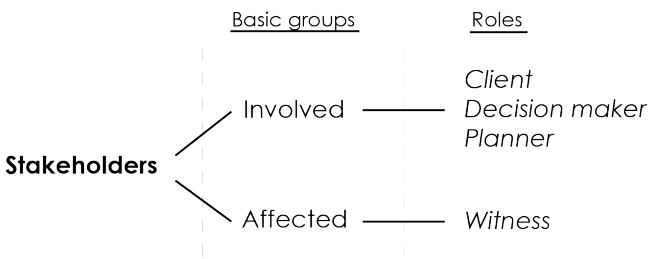


Figure 11: Enumerated overview of Ulrich's classification.

Although the classification of Ulrich provides an answer to the boundary drawing question of *who to involve or who not to involve* it does not focus, like the classification of Winch and Bonke (2002), on the context of projects. The reason why this project focus is so important is that projects differ from day-to-day production and logistic activities because they are characterized by phases. (Cooper, 1990) Furthermore, these different phases in a project are driven by different goals and activities. Thus, it is conceivable that stakeholder involvement will differ between the different phases of a project. (Achterkamp & Vos, 2007)

Based on these reasons, Achterkamp and Vos (2007) have adjusted the classification and added the phasing of involvement for the roles. In figure 12, the classification of Achterkamp and Vos (2007) can be found. The first difference that can be noticed is the modification of the basic group *affected* into *passively involved*. Additionally, it can be noticed that the role of *planner* is changed to *designer* and *witness* to representative. Designer is defined as: "A *designer contributes expertise within the project and is responsible for the interim deliverables"* and representative as: *"representative is a person who has been chosen to act on behalf of another"*. (Achterkamp & Vos, 2007, p. 8)

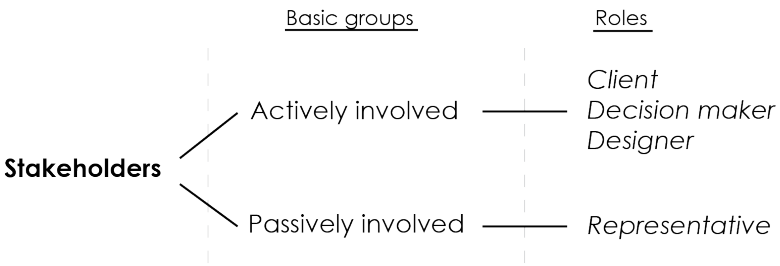


Figure 12: Enumerated overview of Achterkamp and Vos (2007)'s classification.

While the classification of Achterkamp and Vos (2007) looks promising in context of this research., their basic group classification caused interpretation difficulties while discussing it with the graduation committee and several other individuals out of the engineering industry. These difficulties can be explained by the general tendency of stakeholders in the engineering project industry being more commonly referred to as internal and external stakeholders. (Lynda Bourne & Walker, 2008; Chinyio & Olomolaiye, 2009; Eskerod & Jepsen, 2009; Eskerod & L., 2013) Therefore, the classification types actively involved and passively involved will be changed into the classification of Winch and Bonke (2002); internal and external stakeholders.

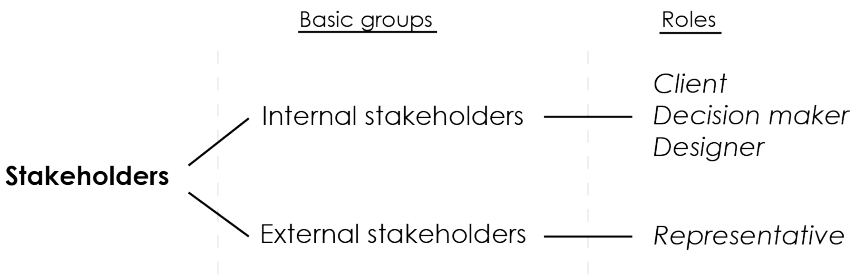


Figure 13: Enumerated overview of classification as used in this research.

## 3.4 How to engage with stakeholders?

After figuring out who, when, and why a stakeholder needs to be involved in the project, it is required to actively approach and engage them so they will and can contribute to the process. This process of engaging stakeholders is closely related to stakeholder management (Eskerod, Huemann, & Ringhofer, 2015), however the two should not be confused. This is because stakeholder management focusses on the overall process of identifying, influencing and managing stakeholders (L. Bourne, 2005; Eskerod et al., 2015; PMI, 2014) and stakeholder engagement on the *"practices that the organisation undertakes to involve stakeholders in a positive manner in organisational activities".* (Greenwood, 2007, p. 318) In other words, engaging with stakeholders is aimed at capturing their inputs into the project development process. (L. Bourne, 2005) In addition, an additional advantage of engaging stakeholders in the decision-making process of a project is that it will increase the sense of ownership of a project. (Shepherd & Bowler, 1997)

However, to have effective stakeholder engagement in a project it is important to effectively communicate with both internal and external stakeholders. (Crane & Livesey, 2003; Olander, 2003) According to PMI (2014), effective communication is achieved when it creates a bridge between stakeholders which are characterized by different cultural and organisational backgrounds, different levels of expertise, and perspectives and interests in the project's outcome. Thus, communication is the connection between stakeholders by which they will be able to transfer information between each other to create a common understanding. In other words, communication can be seen from an information processing perspective, a perspective which is widely adopted and used by several scholars to assess communication in projects. (Adler, 1995; Turkulainen, Aaltonen, & Lohikoski, 2015)

This process of communication (i.e. information exchange) can take place in two forms, namely in a one or two-way (i.e. interactive) process. (Deetz, 1995; Eskerod et al., 2015; Ihlen, 2013; Turkulainen et al., 2015) The first, one-way, can be seen as an information oriented approach, because it is purely aimed at informing a stakeholder about the project, for example by a newsletter or press release. The latter, two-way, has a communication orientation and therefore puts the focus on engaging stakeholders in a discussion (i.e. dialogue) about what, why, how, when something must be done in a project, for example by a workshop. (Eskerod et al., 2015) Although this information versus communication orientation framework is originally developed

for corporate stakeholder management, according to Eskerod et al. (2015) it is also applicable to the context of project stakeholders.

In short, it can be stated that in the act of engaging stakeholders two approaches can be defined. A one-way approach meaning obtaining information or providing information to stakeholders to keep them informed. And, a two-way approach, so-called dialogue, in which a mutual exchange of information is establish.

## 3.5 Ingredients or barriers for collaboration

In the previous section, communication was introduced as means for engaging stakeholders in a project. With it a starting point was created in order to develop fertile (i.e. constructive) collaboration between stakeholders. Nonetheless, the actual collaboration has still not been discussed. This section will explore what elements can be seen as the building blocks of constructive collaboration.

Many scholars have examined the act of collaboration and came up with several models and theories to understand how individuals and/or groups work together, to name a few: Coordination Theory (Malone & Crowston, 1990), Activity Theory (Kuutti, 1991), Task Manager (Kreifelts, Hinrichs, & Woetzel, 1993), Action/Interaction Theory (Fitzpatrick, Kaplan, & Mansfield, 1996), and Object-oriented Activity Support (Teege, 1996). However, these theories and models all have an instrumental point of view in which they put the focus on technology to improve collaborating activities. With these theories and models the question '*what do people do while collaborating?'* can be answered. However, the question *'what people need to do?'* remains unanswered. (Soliman, Braun, & Simoff, 2005) By neglecting the approach, context, implementation, and technology Soliman et al. (2005) arrived at the constants in every collaboration. With these constants they have constructed a framework which outlines the eight essential ingredients of collaboration. Due to this universal and independent approach in their study on the key components to collaboration, their framework will be used in this research. The eight ingredients of successful collaboration according to Soliman et al. (2005) are:

- **People**: Two or more people are needed.
- **Shared space**: A bounded environment is required in which participants can communicate.
- **Time**: Without an investment in time collaboration can not exist.
- **Common objective**: Participants need to have a common objective.
- **Focus on objective:** Participants need to be focussed on achieving the common objective.
- **Common language**: To effectively communicate a common language is needed among participants.
- **Knowledge in the area of the objective**: Participants need to have knowledge in the area of the objective.
- **Interaction:** To engage the previously mentioned ingredients and to achieve the common objective, interaction is needed.

Although Soliman et al. (2005) present the eight aspects as essential ingredients, they can also be interpreted as barriers to successful collaboration. (Patel, Pettitt, & Wilson, 2012) For example, when stakeholders speak a different language due to their difference in discipline background there is a reasonable chance of miscommunication or misinterpretation of information. Therefore, the eight ingredients in this research will also be referred to as barriers in order to have successful collaboration.

## 3.6 Conclusion

By asking several questions this chapter has identified stepping stones required to develop constructive collaboration among stakeholders. However, before these stepping stones were identified a narrower definition was chosen for a stakeholder. This to prevent misinterpretation of the notion in this research. The first stepping stone is focussed on the identification of stakeholders. This identification process uses the *issue*, which is at the core of any project, to search for relations between stakeholders and the *issue* at hand. These relations can be related to the Power, Legitimacy or Urgency of a stakeholder. The result of this stepping stone is a list with stakeholders relevant to the issue at hand. However, not all stakeholders are equally relevant so in stepping stone two, stakeholders are classified. At a high level they are classified as internal versus external stakeholders and on a more detailed level on the basis of their role in the project. The succeeding stepping stone then determines how to engage the stakeholders. This engagement can have a one-way or a two-way communication character. Lastly, stepping stone four introduces eight key ingredients, or if not present barriers, to constructive collaboration. Together, these stepping stones map the route to developing constructive collaboration between stakeholders in a project.

# 4 Research Methodology

In this chapter the research methodology for the assessment of VDC in practice (case study) and testing of the road map of constructive collaboration (questionnaire) will be elaborated. However, before this will be done an elaboration will be provided on the selected organisation.

## 4.1 Organisation selection

For the data gathering, the Dutch Engineering and Project Management Consultancy Royal HaskoningDHV (RHDHV) is selected. RHDHV is an independent organisation of 6,500 employees with clients in more than 150 different countries. With a net turnover of €667 million in 2015 RHDHV is the 4th largest Design and Engineering organisation in the Netherlands. (Royal Haskoning DHV, 2015a) Globally, RHDHV has a 46th place in Top 150 Global Design Firms. (ENR, 2016) The reason for selecting RHDHV is that it is the first Design and Engineering organisation in the Netherlands that has adopted the VDC methodology of the Stanford University.

The overall organisational structure of RHDHV, see figure 14, consists of four business lines; Industry & Building, Maritime and Aviation, Transport & Planning, and Water. Underneath these business lines there are in total twenty-one different business units. Each of these business units are focussed on a different market based on geographical orientation and/or expertise. For this research, the Netherlands oriented business units of the business lines Industry & Buildings and Transport & Planning were selected. This is by reason that majority of the Stanford certified[5] VDC-experts fall within those two business lines. (RHDHV, 2016)

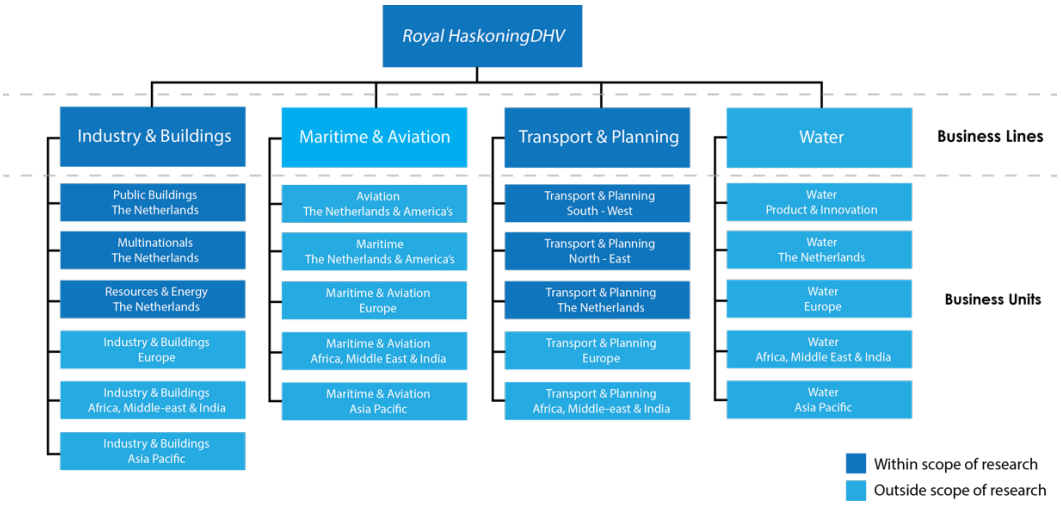


Figure 14: Organisational chart Royal HaskoningDHV

[5] A certified VDC-expert has successfully completed the VDC Certificate Program of CIFE at the Stanford University of California.

## 4.2 Explanatory case study

A case study with an explanatory character will be performed to gain better understanding of how Royal HaskoningDHV applies the VDC methodology in its engineering projects. The reason for choosing an explanatory case study is that they are considered appropriate for *how* and *why* research questions, as for research question three, and that it is a useful method to provide a descriptive explanation of how something happens or happened. (Yin, 2009)

### 4.2.1 Case study design

The overall case study design consists out of two parts. The first part is focussed on assessing RHDHV's internal policy document on the application of VDC in engineering projects. The second part will assess how RHDHV applies the VDC methodology in engineering projects (i.e. in practice). This assessment will follow the method of Yin (2009) for a multiple case study. The choice for this particular method was made for the following reason. In order to reduce the possibility of exceptions and the fact that the results of a multiple case study are considered more compelling and therefore more robust (Herriott & Firestone, 1983) has led to the decision of conducting a multiple case study.

### 4.2.2 Case study protocol

In order to guide this study with the collection, analysis, and interpretation of the information a case study protocol is formulated. This case study protocol will be presented below.

#### 4.2.2.1 Data gathering

The data for assessing RHDHV's internal policy on the application of VDC in engineering projects will be derived from internal databases: Insight (intranet), Box (cloud storage), and VDC knowledge group site.

For the practical application of VDC by RHDHV two engineering projects are selected. For the first project Centrum visie Zeist was selected and for the second Railway crossing Ermelo. A detailed of the selection procedure of these projects can be found in appendix B. The data for these two projects will be derived from project documentation, semi-structured interviews, and VDC-session observations[6].

The interviews are held in a semi-structured format and due to the explanatory nature of the study, interviewees were not informed about the preliminary results of project documentation analysis. The purpose of the interviews was to validate the findings of the session analyses, search for grey areas, and the reasoning behind the choices made during the project.

#### 4.2.2.2 Data analysis

As mentioned the data will be gathered from internal databases, project documentation, session observations, and interviews. However, for this data to be meaningful it must be analysed.

[6] VDC-session observations are only applicable to project Centrum visie Zeist.

The data gathered from the session observation and interviews will first be coded and hereafter analysed on the basis of reoccurring and/or remarkable words, topics, and issues. This has as objective to search for interesting aspects, similarities, and differences between the interviewees and/or observations.

Furthermore, to get a sense of how the VDC-process is structured by RHDHV the VDC-sessions will be visualised by the aid of process models. These models will be based on the project documentation.

## 4.3 Questionnaire

The in chapter 6 developed road map for constructive collaboration is based on a synthesis of both scientific literature and practical observations. In this synthesis several assumptions were made to be able to integrate the different aspects into one road map. In order to validate these assumptions a questionnaire was distributed. The protocol of this questionnaire will be presented below.

### 4.3.1 Data gathering

For this research an online questionnaire is chosen because it provides an efficient method for gathering an extensive data set that enables the researcher to formulate a broad view (i.e. helicopter view) on a certain topic. (Johannesson & Perjons, 2014; Verschuren & Hartog, 2005) In the following sections a more elaborated explanation on the data collection procedure, questionnaire design, and pilot testing will be provided.

### 4.3.2 Data collection procedure

The data collection procedure consists out of three steps; demarcation of the research population; define a strategy to approach the research population; and lastly in what format the internet questionnaire will be distributed.

**Demarcation of research population**

As mentioned earlier the questionnaire will be distributed within RHDHV and among the VDC certified experts of the business lines Buildings and Transport & Planning. By these criteria the total research population consists out of 34 VDC-experts, of which 15 of Buildings and 19 of Transport & Planning.

**Strategy of approach**

The questionnaire was spread among the research population by means of a personalized email. Furthermore, a cartoon related to the subject of collaboration was added to the emails. This had as purpose to increase the initial response rate. The first invitation was sent on 19$^{th}$ of May. Hereafter, two reminders were given. The first reminder was send by email on the 24$^{th}$ of May and the second was performed by telephone on the 30$^{th}$ of May. Lastly to ensure confidentiality, the respondents were informed that their answers would be made anonymous and only be used for the purpose of this research.

**Questionnaire tool**

The questionnaire was constructed with the aid of a Google Form. A Google form is a free of charge web-based tool to design questionnaires. The choice of using a Google Form is based on the fact that the pilot sessions indicated that the Google Form has shown to be more user-friendly than the proposed alternative of a Typeform[7] format.

#### 4.3.2.1 Questionnaire design

On the basis of the road map formulated in chapter 6 a set of closed questions and statements with a black and white perspective are formulated. A black and white perspective is chosen to prevent misinterpretation of the statements. On the basis of these statement the respondent is asked to express its opinion on a fully labelled five-point Likert-scale ranging form *totally disagree* up to *totally agree*. Although this provides the opportunity for the respondent to avoid taking a side with regards to statement, an aspect which heavily debated in the literature (Garland, 1991; Matell & Jacoby, 1971; Preston & Colman, 2000), the choice is made to include the neutral opinion. By reason of that a five-point scale is considered more reliable than a four-point scale. (Preston & Colman, 2000) Thereby, the researcher is of the opinion that the respondent must not be forced into taking a particular stand with regard to a statement.

Furthermore, the overall design of the questionnaire can be divided into five parts: introduction, general information, preparation, collaboration during preparation, and feedback. These five parts will be briefly elaborated below, the complete questionnaire as distributed among the VDC-experts can be found in appendix C.

**Introduction**

The questionnaire starts with a short introduction explaining the purpose and context of the questionnaire. Hereafter, the respondent will be ensured that the results will used anonymous and only for the purpose of this research.

**General information**

In the first part of the questionnaire several general questions are asked to the respondent. These questions allow the researcher to categorize the respondents on the basis of their business line, project experience, and attitude towards the VDC methodology. Furthermore, a general statement to test the assumption that one of the differences between Building and Transport & Planning projects is that they differ in the amount of stakeholders involved. This to search for a possible correlation between the amount of stakeholders involved and answers provided by the respondents.

**Preparation**

The second part of the questionnaire presents four statements to the respondent. These are formulated to measure their attitude with regards to the assumptions that preparation is the key

[7] Typeform is a free of charge web-based survey-tool.

to a successful VDC-process, preparation is limited to internal stakeholders, and all stakeholders should be trained with the methodology.

**Collaboration during preparation**

In part three of the questionnaire the respondent is asked to present their opinion with regards to eight statements. These eight statements are formulated on the basis of the eight aspects of collaboration as defined in the road map for constructive collaboration.

**Feedback**

Lastly, the questionnaire will conclude with the opportunity for the respondent to provide comments and additional feedback.

#### 4.3.2.2 Pilot sessions

Before the questionnaire was distributed among the respondents four pilot-sessions were held. Two sessions were held with people with knowledge of the research area and two without any knowledge. Based on the feedback of these pilot-sessions the questionnaire was adjusted. In appendix C the results of these pilot-sessions can be found.

### 4.3.3 Data analysis

As mentioned in the questionnaire design a five-point Likert scale is applied. Due to this the data derived from the questionnaire will be on an ordinal scale. (Mu, Mauthe, Tyson, & Cerqueira, 2012) This means that there is a difference between the Likert categories but that the exact distance between the categories cannot be defined. (Carver & Nash, 2012; Mu et al., 2012; Vocht, 2009) Furthermore, the two groups (business lines) have both a relative small sample size. Meaning a sample size of $n < 30$. (Carver & Nash, 2012; Vocht, 2009) For those reasons and in order to perform reliable and valid analysis on the data one can only consider descriptive and nonparametric analysis techniques. (Mu et al., 2012)

Descriptive statistics uses the data by ordering and presenting it in form of frequency tables and/or graphs. (Vocht, 2009) This has as objective to learn more about the data derived from the population. Non-parametric (and parametric) statistics on the other hand is aimed at making an inference about a research population on the basis of data gathered by a sample and will produce statistical measures to determine the likelihood (i.e. probability) of the inference. (Carver & Nash, 2012; Vocht, 2009) Nonparametric statistics differs with parametric statistics on the fact that it focusses on the order or ranking and not on the numerical values of the scores. (Mu et al., 2012) So instead of using the means (parametric statistics) one will use the median (non-parametric) to compare populations.

#### 4.3.3.1 Descriptive measurements

In this research the descriptive measurements of *median, minimum and maximum value, quartiles, Skewness,* and *Kurtosis* will be applied.

The descriptive measure *median* will be used to determine the general attitude of the research population and/or groups regards a statement. *Median* is the middle value of a dataset which is ranked form small to large. (Vocht, 2009) In this research a statement with a median of four

(Likert scale category: Agree) will be considered as valid. But a statement with a median of three (Likert scale category: neutral) or lower as an invalid/incorrect statement.

The *minimum and maximum value, quartiles, skewness,* and *kurtosis* of a dataset will be assessed for determining the distribution characteristics of the data within a set. In other words, *how far apart* or *how close* are the answers of respondents on a particular statement.

#### 4.3.3.2 Non-parametric statistical methods

In this research a Chi-square goodness-of-fit test will be performed to determine if the derived sample is representative for the research population. A Mann-Whitney U-test to determine if the business line to which a respondent belongs has an effect on the provided answers. And, a Kruskal-Wallis test to determine if the self-rated or measured experience of a respondents has an effect on the answers provided. Below the just-mentioned non-parametric statistical methods will be briefly elaborated.

**Chi-square goodness-of-fit test**

To asses if a data sample fits the profile of the population (i.e. is representative) a chi-square goodness-of-fit can be performed. (Carver & Nash, 2012) For this test the observed frequencies will be compared with the expected frequencies. If then the chi-square value is close to zero, the null-hypothesis will be retained. (Vocht, 2009)

**Mann-Whitney U-test**

For determining if two samples on an ordinal scale can be considered taken from the same population a Mann-Whitney U-test can be performed. (Vocht, 2009) The Mann-Whitney U-test can be considered as the nonparametric equivalent of the independent samples Student's T-test. The general Null-hypothesis for the Mann Whitney U-test is that both samples are taken from the same population. Hence, no significant difference exits between the two groups. (Carver & Nash, 2012; Vocht, 2009)

**Kruskal-Wallis test**

The Kruskal-Wallis test is in essence similar to the Mann-Whitney U-test, however instead of two independent samples it requires at least three independent samples. (Carver & Nash, 2012; Vocht, 2009) The non-parametric equivalent of the Kruskal-Wallis test is the one-way analysis of variance (i.e. ANOVA). (Carver & Nash, 2012) The general the Null-hypothesis for the Kruskal-Wallis is that all samples are taken from the same population. (Carver & Nash, 2012; Vocht, 2009)

#### 4.3.3.3 Data analysis tool

To conduct the descriptive and nonparametric analyses in this research IBM's statistical software package SPSS Statistics will be used. However, before the data of the questionnaire can be used for descriptive and nonparametric analysis in SPSS and in order to prevent inconsistency in the dataset the data must be coded (Vocht, 2009) In appendix C an enumerated overview of the data codification can be found.

# 5 Virtual Design and Construction in practice

In this section, an explanatory case study will be conducted to gain more insight in the way RHDHV has dealt with absence of formal processes and methods to structure a VDC-project process. The case study protocol guiding this study can be found in chapter 4 and the question guiding this case study below.

RQ3: *How is Virtual Design and Construction applied by RoyalHaskoningDHV in its engineering design projects?*

In order to provide a well substantiated answer, RHDHV's interpretation of the VDC methodology will be provided. Hereafter, internal policy documents of RHDHV will be examined on methods and/or guidelines aimed at structuring a VDC-project process. Lastly, two engineering projects in which the VDC methodology is applied will be studied. As mentioned earlier in the research methodology, for the first case project Centrum visie Zeist was selected. At the time this research was conducted, Centrum visie Zeist was in the definition phase of the project. The fact that the project was in progress provided the advantage that the researcher, besides a document analysis and interviews, was able to observe two VDC-sessions and witness the VDC-process first-hand. By having this opportunity, a more thorough study was made. The second case selected, railway crossings Ermelo, is a completed project and related to the conceptual design phase. For this case, information was gathered by conducting an analysis of project documentation and two interviews with project team members.

## 5.1 Royal HaskoningDHV and VDC

The fact that projects are getting more complex, project failure is still common, and that the amount of information is ever expanding has also caused engineering firm RHDHV to re-evaluate its current project approach. RHDHV's key driver in this is that their current project approach is causing projects not able to meet the targets for a positive execution result. With a positive project execution result is meant; projects delivered according to the financial agreement with the client. Currently, RHDHV's project execution result is at a level of 54% against a target of 70% for 2016. (Royal Haskoning DHV, 2016)

On the basis of these issues, RHDHV has adopted the VDC methodology in its organisation. RHDHV defines VDC as the process of working simultaneously and real-time with all involved actors on a (virtual) model, while at the same time considering process and organisation aspects. In other words, VDC makes it possible to deal with process, product and organisational aspects of a project simultaneously. (Royal Haskoning DHV, 2015c) In the preceding sentence, '*virtual*' was placed between brackets, because in theory VDC can be applied by using as much as a couple of whiteboards and post-its. However, often a virtual product model, a so called Building Information Model (BIM), acts as the basis at RHDHV. Adding a virtual model to VDC creates the advantage of multiple disciplines and parties working simultaneously on the same model and trying out many different possible solutions. In figure 15, RHDHV's interpretation of the VDC-methodology is visualised. As can be seen, RHDHV interprets the I-Room also as key aspect in the methodology. In their perception it is the piece in the puzzle that will combine the Product, Organisation, and Process of a project. (Royal Haskoning DHV, 2015c)

The effect of applying VDC according to RHDHV is that all involved parties can witness first-hand what the effects of a proposed solution are. These new insights result in higher decision quality, faster decision-making and stronger support among actors. The application of VDC at RHDHV has already resulted in a reduction of failure costs of 50% and lead time of 35% in projects. (Royal Haskoning DHV, 2015c)

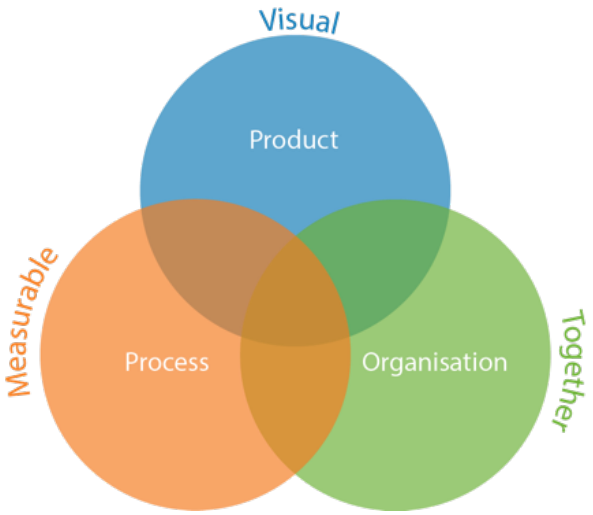


Figure 15: Visualisation of VDC-process. (Royal Haskoning DHV, 2015c)

## 5.2 VDC methods and guidelines

For the assessment of RHDHV's internal policy documents related to the application of the VDC methodology, the following databases were consulted: insight (intranet), box (cloud storage), and VDC knowledge group site.

On both box and insight, no information about methods and or guidelines aimed at structuring a VDC-process were found. The VDC knowledge group site was the only database that contained VDC-process related documents. An example of such a document is shown in figure 16. As can be seen in the example, although the road map does provide a general overview of how to set up a VDC-project, it does not address in detail how this exactly must be done. In other words, it does not present useful methods to actually prepare and perform a VDC-project. Furthermore, the documents found on the knowledge group site indicated a level one maturity of VDC at RHDHV. One example indicating this can also be found in figure 16, because it advises the use of visual models and metrics when applying VDC.

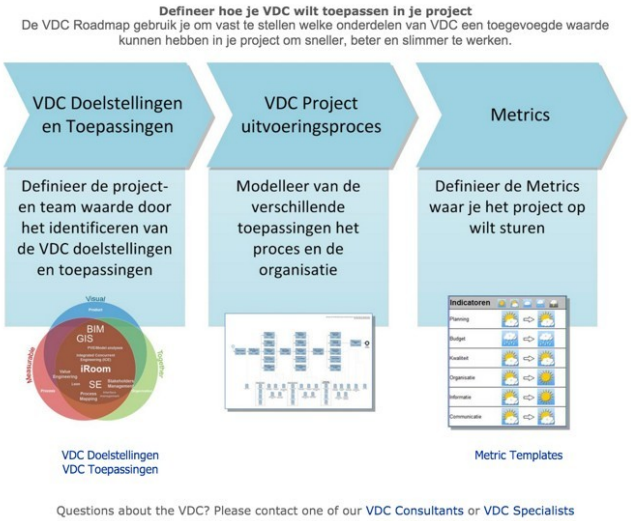


Figure 16: Example of VDC-process documentation RHDHV - *VDC road map*.

On the basis of assessed databases, the presumption arose that RHDHV does not prescribe a certain method or has a set of guidelines to structure a VDC-project process. To verify this presumption several RHDHV VDC-experts were contacted. From contact with J. Rampaart on the 18th of January 2016, a first indication was that the presumption could not be refuted. In addition, the interview with Dijkstra, see appendix B, in which he stated: "*…to my knowledge there is no process book or standard approach for applying VDC within RHDHV"* could not refute this. Lastly, VDC knowledge group chair M. Post was approached by mail on the 21st of January 2016 with a request for VDC-process related documents. However, she stated that RHDHV does not have any specific documents aimed at structuring or guiding the application of VDC in a project. In other words, M. Post confirmed the presumption that RHDHV does not have methods or guidelines to structure a VDC-project. Therefore, it was concluded that RHDHV is not in the possession of documents stating a prescribed method or set of guidelines on how to manage and structure a VDC-project process.

## 5.3 Application of VDC in engineering design projects

This section will perform a multiple case study to create a proper understanding of the application of VDC by RHDHV in its engineering design projects.

### 5.3.1 Case I: Centrum visie Zeist

In this first case project, Centrum Visie Zeist will be studied. This is done by first providing a case introduction. After that, the results of the project documentation analysis, sessions analysis, and interviews are presented. See appendix B for the case study data.

#### 5.3.1.1 Case introduction

The municipality of Zeist is facing the problem that its city centre is threatened by a decline in the number of non-daily shoppers, high rate of retail vacancy, and public space being of insufficient quality. Besides this, the current infrastructure in and around the city centre is found to be unclear and not capable of providing a smooth traffic circulation. (Royal Haskoning DHV, 2015b) Due to these issues, the once so vibrant city centre of Zeist is rapidly decaying. In order to turn the tide, the municipality of Zeist wants to redevelop its city centre. The area of subject is divided into three subareas which will be addressed in separate phases. By redeveloping these areas, the municipality of Zeist wants to make its city centre future-prove, appealing, and coherent, so that it in the year 2020 and thereafter it is capable to deal with social, cultural and zeitgeist changes. (Gemeente Zeist, 2015)

In the first phase of the redevelopment, the municipality of Zeist has formulated a *Centrumvisie*[8] and a *Beeldkwaliteitsplan*[9] in collaboration with stakeholders which were selected by the municipality of Zeist. (Zeist, 2016) By combining the two documents, a shared vision about the future of the city centre is presented. In other words, these two documents will act as point of departure for the next phase. The role of RHDHV in this project is that they were asked by the municipality of Zeist to manage the next phase of the project. This second phase covers the following activities; construct support among the stakeholders (definition phase), design (conceptual design phase), creating technical drawings (technical design phase), and provide support during the procurement process. (Royal Haskoning DHV, 2015b) In order to guide the project process, RHDHV has suggested to use Virtual Design and Construction as method to structure the process and created support among the stakeholders. However, it must be mentioned that although RHDHV uses the VDC methodology throughout the project, the notion VDC is not specifically mentioned. Instead, they have reframed the notion VDC as a design dialogue. (Rampaart, 2016; Royal Haskoning DHV, 2015b) In the project approach, this design dialogue is made up out of three steps. The first step is focussed on the formulation of a design catalogue. The second step is focussed on the creation of a detailed layout design for the first subarea and a concept design for the whole area. Lastly, the third dialogue is focussed on the creation of a detailed layout design for the other two subareas and the start of the procurement phase. (Royal Haskoning DHV, 2015b)

[8] Strategic document of the Municipality of Zeist with a plan of action for the redevelopment of the city centre.
[9] Bundle of sketches with design possibilities for the city centre.

#### 5.3.1.2 Project documentation and session observations

From analysing the project documentation, dilemma session, and area and framework session, the following conclusions can be drawn. The analysis leading to these conclusions can be found in appendix B.

First of all, the application of VDC in project Centrum visie Zeist can be marked as a maturity level one, because the project's product, organisation, and process were made visual and measurable. In addition, the overall application of VDC in the definition phase of project Centrum visie Zeist can be characterized by the divergence and convergence of information. Furthermore, the main purpose of VDC in this project phase was to guide the decision-making process while maintaining and constructing support among the stakeholders. The role of RHDHV in this process was not to act as the problem solving party, but as a facilitator who guides the stakeholders towards a supported and feasible solution. This process of providing guidance is structured in advance by RHDHV in the form of a session script. However, observations during the two sessions showed that this structured approach still included some degree of flexibility, because it was possible to deviate from the script during the sessions. Additionally, the analysis of the session observations has shown that there is a correlation between the stakeholders attending a VDC-session and the information available during a session for the purpose of decision-making. Overlooking or just not inviting stakeholders to the process has shown to be harmful to the efficiency of the decision-making process, because decision-making must be postponed. Lastly, unsufficient preparation of both internal and external stakeholders prior to a VDC-process let to misalignment in expectations and level of detail in which information was discussed during a session. Eventually, this let to unexpected human behaviour of participants which had significant impact on the overall decision-making process of the VDC-sessions.

#### 5.3.1.3 Interviews

As mentioned in the case study protocol, see chapter 4, the interviews were conducted with Dijkstra (2016) and Rampaart (2016) in a semi-structured format. They had the purpose to validate the findings of the session analyses, search for grey areas, and provide the reasoning behind the choices made during the session. The interviews, which can be found in appendix B, were analysed on the basis of four topics: VDC as methodology, information process structure, stakeholders, and human behaviour.

**VDC as methodology**

Both Dijkstra and Rampaart do not see the VDC methodology as a tool that can be applied within a traditional project approach, but as a different working method for a project itself. It is considered as a method in which collaboration between parties is a key ingredient. According to Dijkstra and Rampaart, the methodology has positively influenced the project process. Dijkstra emphasizes this by stating that the application of VDC has made the decision-making process traceable, it allowed more information to be gathered, and more support to be created among the stakeholders. On the other hand, Rampaart is even more positive about the application of VDC. In his opinion, VDC has given the potential aimlessly process direction, keep information pure, and establish support among stakeholders. Additionally, he believes that achieving the same result with a traditional project approach would have cost a lot more time and effort.

**Information process structure**

From the project documentation and session observations analysis it was concluded that a VDC-session has a clear information structure with clear input and output and an integrated degree of flexibility to deviate from the script. Both Dijkstra and Rampaart confirm that a clear information process structure can be identified in a VDC-session. According to Rampaart, this information structure can be seen as a chain of events in which unprocessed information is enriched at every shackle. Between each shackle, tools such as visualisation of information or structuring of information are used to stimulate the creativity during the process. The result of the chain of events is that unprocessed information is converted into knowledge which can help to achieve the session objective. Dijkstra confirms this, but defines these events as discussions in which the information forms the fuel of the discussion. In addition, Dijkstra states that it is important to keep the level of detail of the information throughout a discussion at the same level. If not, this could lead to irrelevant discussions that harm the process.

However, the aspect of flexibility in the VDC methodology is seen differently. Dijkstra believes that the more flexible a session is the better your session results are. Rampaart states that a VDC-session is as flexible as you want it to be. It is an aspect of VDC that can be used if you think that your session objective is in jeopardy.

The correlation between attending stakeholders and available information was only confirmed by Rampaart. Rampaart underpins that the objective of a session is strongly correlated with the invited stakeholders and information needed to achieve the objective. Lastly, both interviewees revealed two other aspects related to the efficiency of an information process in a VDC-session. First, it is important that all information is checked with the associated stakeholder(s), because if incorrect information is used an irrelevant discussion could start. This could be a potential risk to the overall process of the session. Second, all information gathered, processed and shared during a session should be captured in one single place, e.g. PowerPoint sheets. This also includes non-viable options or suggestions. The reason for this is to ensure traceability of the decision-making process.

**Stakeholders**

In the two questions related to this topic the interviewees were asked if they thought VDC was used in the communication and how stakeholders were selected to be invited to the sessions. According to both interviewees, VDC as concept was not used in the communication between the different stakeholders. Rampaart explains this by saying that the name of VDC is a poor translation of how he sees the methodology. So in order to prevent miscommunication, VDC was not explicitly used in the communication.

The identification and selection of stakeholders which were invited in the first two sessions was performed by the municipality of Zeist. However, if RHDHV would have done the selection they would have conducted a basic stakeholder analysis. A basic stakeholder analysis does not refer to a predetermined method, but to a method based on their own professional experience. In addition, Dijkstra states that if RHDHV had performed the stakeholder analysis based on their method it was most likely that they also would have missed stakeholders. By reason of the fact that this also occurred in previous projects.

**Human behaviour**

During the session there was a clear indication that human behaviour had a significant impact on the session. This observation is acknowledged by both Dijkstra and Rampaart. However, both interviewees see this aspect in a different light. Dijkstra explains that the stakeholder group's state of mind is an aspect that needs to be balanced by the session facilitator. In other words, he or she is the one that can turn this seemingly negative aspect into something positive. Although Rampaart confirms that the facilitator can influence this aspect, he underpins that the state of mind of the project team is equally or even more important than the group's state of mind. The reason for this is the fact that the attending stakeholders have a sense of ignorance meaning that they must be guided by the whole project team during the session.

### 5.3.2 Case II: Railway crossings Ermelo

For the second case study, project Railway crossings Ermelo will be studied. In this paragraph the result of the case study will be presented. This is done by providing a case introduction followed by an elaboration on the results of the project documentation analysis and interviews.

#### 5.3.2.1 Case introduction

The railway line between Utrecht and Zwolle is perceived as a physical barrier for the traffic flow between Ermelo-West and Ermelo's city centre. It is expected that in the near future this barrier function will aggravate, because the train intensity on the line will increase and therefore the rail crossings will be closed more often. In other words, the road between the two areas will be blocked more frequently. In order to deal with this aggravating situation, Prorail has asked RHDHV to look at alternatives for the railway crossings: Horsterweg, Stationstraat, and Telgterweg. See figure 17 for their geographic location. In response to this tender request, RHDHV has proposed to use the method of VDC to guide the project process. (Royal Haskoning DHV, 2012)


Figure 17: Scope of project - Railway crossings Ermelo. (Google maps)

#### 5.3.2.2 Project documentation

After examining the project documentation and the two session scripts, the following conclusion can be drawn.

The overall project process can be seen as a funnelling process in which each session forms its own sub-process characterized by clear input/output and diverging/converging of the project scope. Secondly, the activities related to the different project processes are structured in ten work packages based on their topic. In these ten work packages, six process related aspects were found describing the importance of information management, how relevant stakeholders are determined, and how information is gathered, structured, evaluated, and shared.

Similar to project Centrum visie Zeist, the role of RHDHV in the project was to guide the stakeholders towards a supportive and feasible solution. Moreover, this process was guided by a structured approach in the form of a session script and presented a certain degree of flexibility. This is a result of the transfer of a script item from one session to the next session. Lastly, the application of VDC in project Ermelo can be seen as level one maturity, because of the use of visualisations like a BIM-model and metrics.

#### 5.3.2.3 Interviews

The results of the interviews with Roselaar (2016) and Zutt (2016) will be discussed in a similar manner as for the case Centrum visie Zeist. They will be analysed on the basis of the following four topics: VDC as methodology, information process structure, stakeholders, and human behaviour. The transcripts of the interviews can be found in appendix B.

**VDC as methodology**

According to Roselaar, the methodology of VDC can be seen as a process method which is based on the concept of converging and diverging the project context and creating support and collaboration among stakeholders. On the other hand, Zutt describes VDC in a more technical sense by defining VDC as a method in which project information is made visual with the purpose of making it easier to understand for others. In addition, Zutt makes the remark that it will ensure a feeling of solving issues together is created. Both interviewees are of the opinion that VDC has positively contributed to the project. By applying the VDC methodology, more was done by using the same amount of budget and time in comparison with a traditional project approach. However, Roselaar is a bit more sceptical, because he thinks that although it has brought many positive effects it also has disadvantages.

**Information process structure**

From the project documentation analysis of project Ermelo, a process structure with a clear input/output and an intermediate process characterized by diverging and converging of the project context was identified. The aspects of clear input and output was confirmed by both interviewees. However, Roselaar describes the process in between as difficult to predict. Furthermore, Zutt describes it as a process in which triggers, like design alternatives, are used to discuss information.

Zutt perceives the flexibility of the VDC-session process structure as more flexible than Roselaar, although still very flexible. In addition, they both emphasize that the session objective is most important and that the journey to achieve this objective is as flexible as needed.

Both interviewees describe the way in which sources of information for the session were selected in a similar manner. Both explain that the sources of information were determined by the project team of RHDHV based on their expertise and experiences. The method by which the information was gathered was described identically. They both mentioned that the information was gathered by personal communication with stakeholders, internal documents of RHDHV, and external online databases. In order to prepare the information for a session, both interviewees indicated that only a visual translation of the information was made in the form of a 3D-environment model.

In the process of determining the required information prior to the session, both interviewees admit they have missed a crucial piece of information regarding a high pressure sewer. However, this issue was only linked by Roselaar to an insufficient stakeholder identification prior to the VDC-process.

**Stakeholders**

According to both interviewees, prior to being involved in the project the client was not familiar with the methodology of VDC. However, the methodology was elaborated in the project proposal and explained prior to the start of each VDC-session. According to Roselaar, for the selection of stakeholders, i.e. who will be invited to the sessions, aerial photos in combination with common sense were used. He sees this approach as a form of a stakeholder analysis. Zutt also mentioned this method, but not specifically for project Ermelo. The reason for this was that he was not involved in that particular stage of the project.

**Human behaviour**

Both Roselaar and Zutt confirm that human behaviour has a major impact on the process of a VDC-sessions. In their interview responses they both mentioned that the project team is mainly responsible to balance this aspect throughout the session. By balancing this aspect wisely, it can be used to positively influence the session process. In addition, they also mentioned that besides the behaviour of the project team, to a lesser extent the behaviour of the other stakeholders plays important in the project process as well.

## 5.4 Conclusion

To provide an answer to the following question: "*How is Virtual Design and Construction applied by RoyalHaskoningDHV in its engineering design projects?*" an explanatory case study was conducted. This study included the assessment of internal company documents and two engineering projects in which VDC was applied by RHDHV.

After assessing the internal company databases of RHDHV, the suspicion arose that RHDHV does not prescribe a method or set of guidelines on how to manage information in VDC-projects. In order to verify this, several RHDHV VDC-experts were contacted. They all confirmed the absence of clear documentation on this subject. Therefore, it can be concluded that RHDHV does not have documents prescribing a method or set of guidelines on how to manage the application of VDC in a project.

However, after conducting a study on project Centrum Visie Zeist and Railway Crossing Ermelo, although based on personal experience of the VDC-experts, a clear structure was identified in the application of VDC in the projects. The application of VDC by RHDHV is on a maturity level one, because it uses metrics and virtual models, but no computer based information exchange methods. Furthermore, the overall VDC-process in the two projects can be characterized as funnelling processes in which each session has clear input and output. The intermediate process is characterized by a flexible and dynamic process that is aimed at diverging and converging the project context. The role of RHDHV in a VDC-project differs with that of a traditional project, instead of focussing on problem solving, they will act as a facilitator who guides the stakeholders towards a supported and feasible solution to their problem.

Although the process in a VDC-session is structured the run-up to a session remains unstructured in case of RHDHV. This unstructured approach resulted in both projects in less effective decision-making. This less effective decision-making was pointed out by two aspects. First, if one or more stakeholders lack preparation, either an internal or external stakeholder, this will lead to misalignment in expectations and level of detail on which information is discussed. Thereby it causes unexpected human behaviour what has shown to be harmful to the decision-making process. Secondly, overlooking or not inviting stakeholders to a session resulted in another potential threat to the decision-making of a VDC-process. Thereby, it was recognized by all interviewed VDC-experts that the identification of stakeholders was either not performed or performed according to a simplified method based on personal experience.

# 6 Synergy - A road map for constructive collaboration

In this chapter the results of the theoretical (chapter 2) and practical assessment of VDC (chapter 5) will be combined with the stepping stones for constructive collaboration (chapter 3) into a road map for constructive collaboration. Due to the fact that the road map is based on both literature and practice, several assumptions were made to be able to integrate the different elements into one road map. In the following paragraphs first the assumptions will be elaborated and hereafter the road map itself will be presented.

## 6.1 Assumptions

**(1) Preparation is essential to a VDC-process**

As described earlier VDC can be seen as a pressure cooker what can be applied to a project. In it the focus is put on increasing multi-party collaboration, information exchange, and reduce response latency between stakeholders. All with the objective to improve the decision-making quality in a project. However, due to the intensifications of information exchange between stakeholders, preparation can be considered as essential to a successful VDC-process. Furthermore, insufficient stakeholder identification, what is part of the preparation, has shown in the case study to be harmful to the decision-making process of VDC.

**(2) All internal stakeholders should be involved during the preparation of a VDC-process**

This second assumption is based on the fact that the VDC methodology is aimed at increasing multi-party collaboration and reduce response latency between stakeholders. If one or more internal stakeholders are excluded from the preparation this will contradict with the methodology because it will decrease collaboration and increase response latency. In addition, to obtain a comprehensive perspective of the required stakeholders to solve the issue at hand the identification should be performed by multiple stakeholders in a group brainstorm according to the literature. Furthermore, if done individually the practical assessment of VDC has shown that this provides a significant chance of overlooking stakeholders which harmful to the decision-making process.

**(3) Internal stakeholders should be trained with the VDC methodology**

At the base of the VDC methodology are ICE and POP-models. Due to the integration of these methodologies into VDC and the fact that they in itself already differ from the traditional project practice would suggest that knowledge of these theories is needed. Additionally, the case study has shown that untrained internal stakeholders are harmful to the VDC decision-making process because it causes misalignment of expectations and level of detail on which information is

discussed. Therefore, it would be assumed that all internal stakeholders should be trained with VDC prior to attending a VDC-process.

**(4) External stakeholders should be trained with the VDC methodology**

Although external stakeholders in comparison with internal stakeholders are passively involved and less often invited to a VDC-session it would be assumed that also external stakeholders should be trained with VDC to assure efficient decision-making. Additionally, and similar to the previous assumption, the results of the case study have shown that untrained external stakeholders are harmful to the VDC decision-making process. This due to the fact it causes misalignment of expectations and level of detail on which information is discussed. Therefore, it would also be assumed that all external stakeholders should be trained with VDC prior to attending a VDC-process.

**Key aspect of collaboration during preparation**

In chapter 3 eight key elements/barriers for collaboration were presented. These elements were stripped to the bare essence by Soliman et al. (2005) and therefore to make them applicable to the context of this road map some adjustments were made. These adaptations are only of minor nature so that the elements remained close to its original. By doing so the validity of the elements was safeguarded. Below the assumptions per element will be presented.

**(5) People**

For constructive collaboration during the preparation of a VDC-process two or more stakeholders must be involved. This to extract the forming and storming stages of Tuckman (1965) out of the process, as discussed in the introduction, and focus on the norming and performing of the stakeholders in the VDC-process.

**(6) Shared space**

For collaboration to take place during preparation a shared or in order words a bounded environment is required for stakeholders. This to allow interaction between stakeholders and information. Such an environment can either be virtual (online) or physical.

**(7) Time**

Sufficient time for collaboration is essential for developing constructive collaboration during the preparation of a VDC-process. Without it interaction and information exchange between stakeholders will diminish what is contradictory to the VDC methodology because this focusses on increasing these aspects.

**(8) Common objective**

The reason behind the participation of stakeholders during the preparation can differ but they must have a shared objective. By reason that this shared objective will act as linking element and thereby constructs the foundation for collaboration among the stakeholders.

**(9) Focus on objective**

In case the other seven elements are present during the preparation a lack of focus of the stakeholders on the objective can lead to a useless preparation. In order to prevent such an event focus of the stakeholders on their common objective is needed.

**(10) Common language**

In an engineering design project many different stakeholders with different knowledge are involved. (Chinyio & Olomolaiye, 2009) Due to these different expertise stakeholders are tend to speak their own discipline language. Furthermore, when dealing with foreign stakeholders a language difference due to origin can add to this. In order to prevent misinterpretation and miscommunication (i.e. increase effective communication) between stakeholders a common language is needed.

**(11) Knowledge in the area of the objective**

Collaboration is focussed the exchange of information between different stakeholder. This by reason that someone alone has not enough knowledge to solve the issue at hand. Therefore, stakeholders who participate during the preparation need to have knowledge in the area of objective to effectively contribute and collaborate with others.

**(12) Interaction**

Collaboration can only exist when interaction takes place between stakeholders. Therefore, interaction is a key element of the VDC-methodology. In order to ensure interaction between stakeholders in the preparation of a VDC-process it would be assumed that monitoring and stimulating interaction is beneficial of developing constructive collaboration between stakeholders.

## 6.2 A road map for constructive collaboration

In figure 18 the road map for developing constructive collaboration in the run-up to a VDC-process is presented. As can be seen in the figure the road map consists out of four steps: *Identify, Classify, Engage, and Collaborate.* In the following sections these steps will be elaborated more extensively.

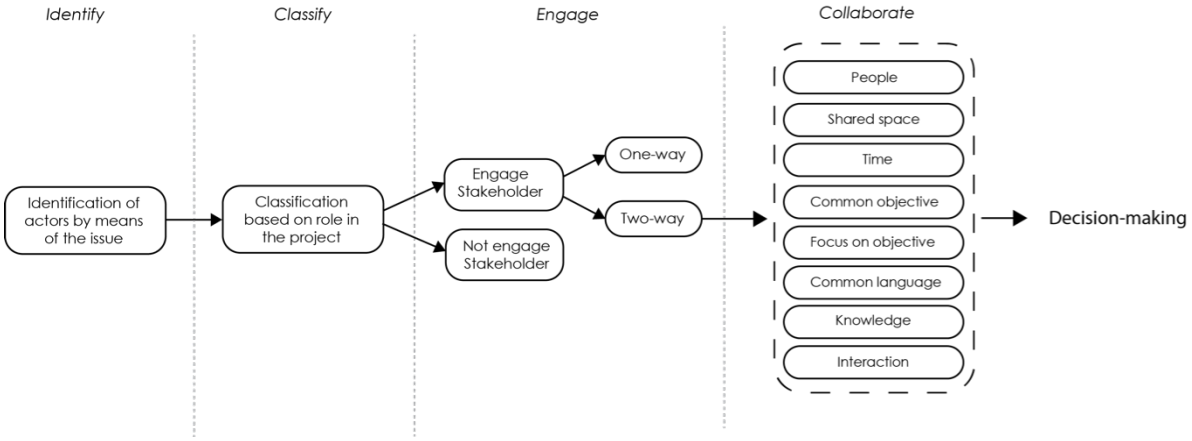


Figure 18: A road map for constructive collaboration.

**Step 1: Identify**

On the basis of the issue of the project or project phase a stakeholder identification will be performed. This identification should be performed by all internal stakeholders which are know at that point in time. The identification will be conducted in the form of a group brainstorm what is aimed at searching for stakeholders which are related to the issue in categories of Mitchell et al. (1997): *Power, Legitimacy,* and *Urgency.* The output of this step is a list with stakeholders who are in one way or another related to the issue at hand.

**Step 2: Classify**

With the output of the previous step a two level classification of stakeholders will be made. On level-one a distinction is made between internal and external stakeholders. In this road map internal stakeholders are defined as: *members of the project team including client, financer, and others who are frequently involved*[10]. An external stakeholder is defined as: *a party or individual which is affected by the project in one way or another but is not frequently involved.* Hereafter, on level-two a classification on the basis of their role in the project will be made. The role of client is defined as *the stakeholder whose objectives are being served* (i.e. is the source of motivation for the project). (Ulrich, 1983) A designer: *as a stakeholder who contributes expertise to the process and is responsible for the interim deliverables.* (Achterkamp & Vos, 2007) And, representative as: *a stakeholder who has been appointed or chosen to act on behalf of another.* (Achterkamp & Vos, 2007) In figure 13 the two-level classification can be found.

[10] A frequently involved stakeholder is a stakeholder who is involved in more than two or more VDC-processes.

**Step 3: Engage**

On the basis of the classification of stakeholders it must be decided how the appointed stakeholders will be engaged to allow them to contribute. This engagement can either be performed in a one-way or two-way fashion. A one-way approach has an information orientation and is merely focussed on receiving or providing the another stakeholder with information. The two-way fashion on the other hand is focussed on mutual exchange of information and discussion of this information in the form of a dialogue.

**Step 4: Collaborate**

Lastly, in step four of the road map the eight element for collaboration must be assessed. This to ensure the establishment of constructive collaboration among the stakeholders instead of just collaborating with each other. If one or more aspects cannot be met this could form a potential barrier for constructive collaboration to take place. What consequently will affect the decision-making in a VDC-process.

# 7 Results of validation

In this chapter the results of the questionnaire will be presented. This will be done by first presenting the results of the descriptive analysis followed by the results of the nonparametric analysis and ending with the feedback of the respondents.

## 7.1 Results: Descriptive analysis

### 7.1.1 Composition of the respondents

As can be seen in table 3 the questionnaire was answered by 32 out of the 34 contacted VDC-experts. This amount is equivalent to a response rate of 94.2 percent.

| Business line | Population | Responses | Response rate |
|---|---|---|---|
| Buildings | 15 | 14 | 93.3% |
| Transport and Planning | 19 | 18 | 94.7% |
| **Total** | **34** | **32** | **94.1%** |

Table 3: Response rate questionnaire.

In figures 19 to 20 the composition of the respondents is visualized in three pie-charts. Figure 22(left) shows that the group of respondents is made up out of 41 percent Building and 59 percent Transport and Planning VDC-experts. Figure 19 (right) visualizes the respondents in a Pie-chart based on their experience with VDC regards to the amount of projects performed with VDC. From this Pie-chart can be seen that the vast majority of the respondents has worked with the VDC methodology in 1 up to maximum of 5 projects. Lastly, figure 20 presents the self rated experience level regarding the VDC methodology.

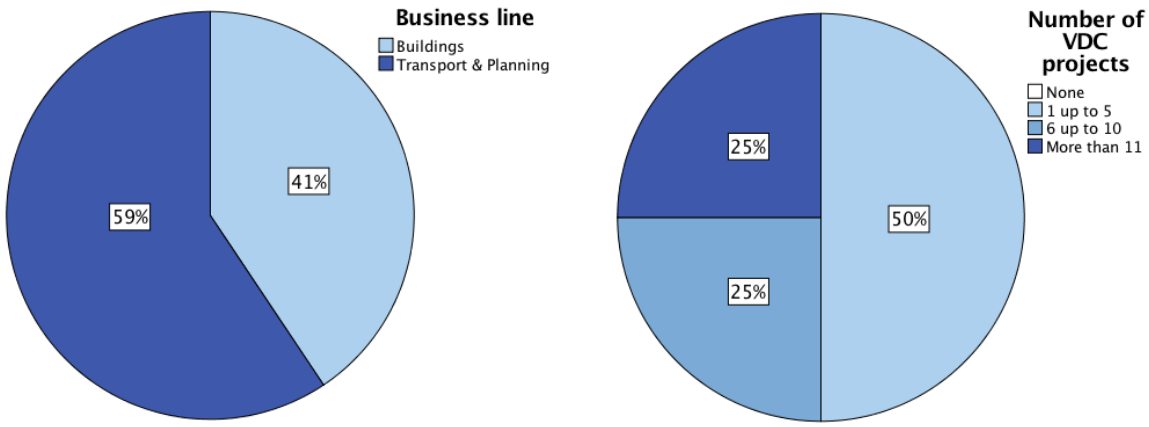


Figure 19: Composition of respondents categorized on business line (left) and number of VDC-projects performed (right).

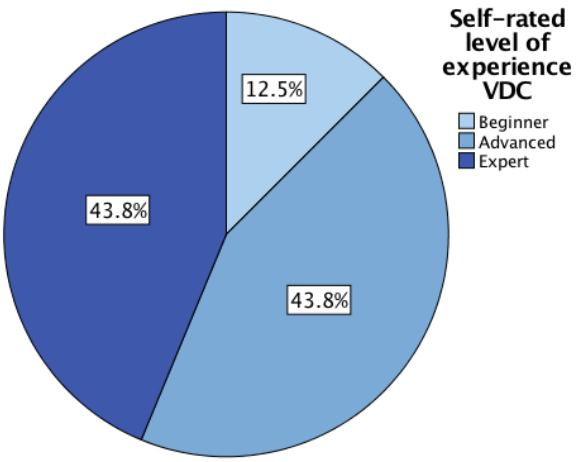


Figure 20: Composition of respondents on self rated level of experience.

### 7.1.2 Central tendency bias

In the design of the questionnaire the choice was made to include a neutral position in the Likert-scale. As already mentioned in the research methodology this has both advantages as disadvantages. On of those disadvantages was that it would allow a respondent to avoid taking a position regards a statement (i.e. central tendency bias). In order to determine if the neutral option was used as an easy way out, the answers of statement categories two and three are counted per Likert category. Category one was excluded because this category contains only one Likert-scale question which had as purpose to test a general assumption and therefore was not related to the road map. The count is summarized in table 4 and visualised as a Pie chart in figure 21. It must be mentioned that the count per category, median, and mean in this particular analysis can only be used to assess a possible central tendency bias and not to draw any other conclusions. From the data presented below it can be assumed that the respondents have not used the neutral position to avoid taking a position. This is by reason that the median has a value of four and that the neutral option is chosen approximately one in every five answers.

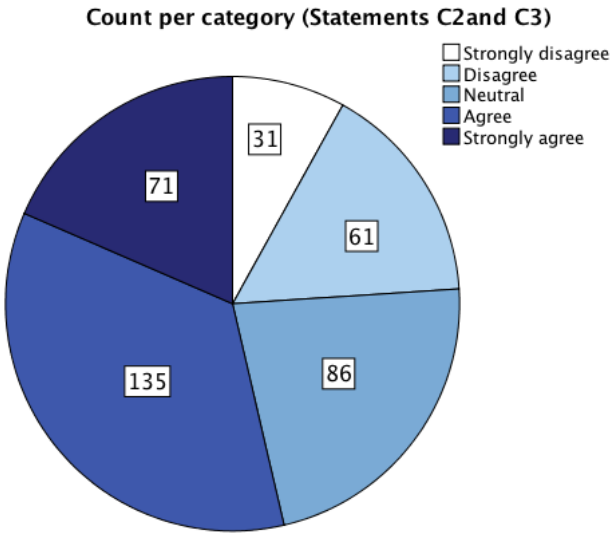


Figure 21: Count per Likert-category in a Pie-chart.

| Score count | | |
|---|---|---|
| N | Valid | 384 |
| | Missing | 0 |
| Mean | | 3.4 |
| Median | | 4 |
| Minimum | | 1 |
| Maximum | | 5 |
| Percentiles | 25 | 3 |
| | 50 | 4 |
| | 75 | 4 |

| Category | Count | Percentage |
|---|---|---|
| Strongly disagree | 31 | 8.1% |
| Disagree | 61 | 15.9% |
| Neutral | 86 | 22.4% |
| Agree | 135 | 35.2% |
| Totally agree | 71 | 18.5% |
| *Cumulative* | 384 | 100.00% |

Table 4: (Left): Frequency table of score counts (right): count per Likert-category.

### 7.1.3 Comparison between business lines

In the figures 22 and 23 the respondents are classified by their business line. This is done to make a rough comparison between the two groups. In figure 22(left) the number of respondents per business line is categorized on the basis of the number of VDC-projects performed. It can be seen that the business line Buildings in comparison with Transport and Planning has a more balanced population. Furthermore, in figure 22(right) the rated added value of VDC in a project is presented. It can be seen that both business lines perceive the added value of VDC in a project as significant however Transport and Planning generally rates the added value of VDC in a project higher.

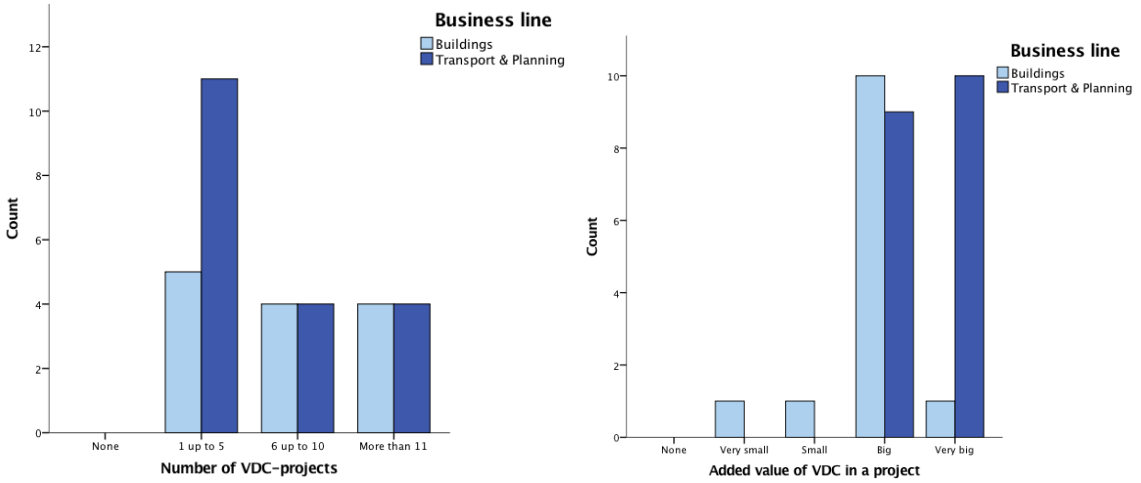


Figure 22: Number of VDC-projects per business line (left) and Perception of added value per business line (right).

In the questionnaire a question was included which asked the respondent to rate how experienced they considered themselves regarding the VDC methodology. This rating is plotted per business line in figure 23 against their experience in terms of VDC-projects performed. At first sight there appears to be no clear correlation between the number of VDC-projects performed and the self-rated level of experience in both business lines.

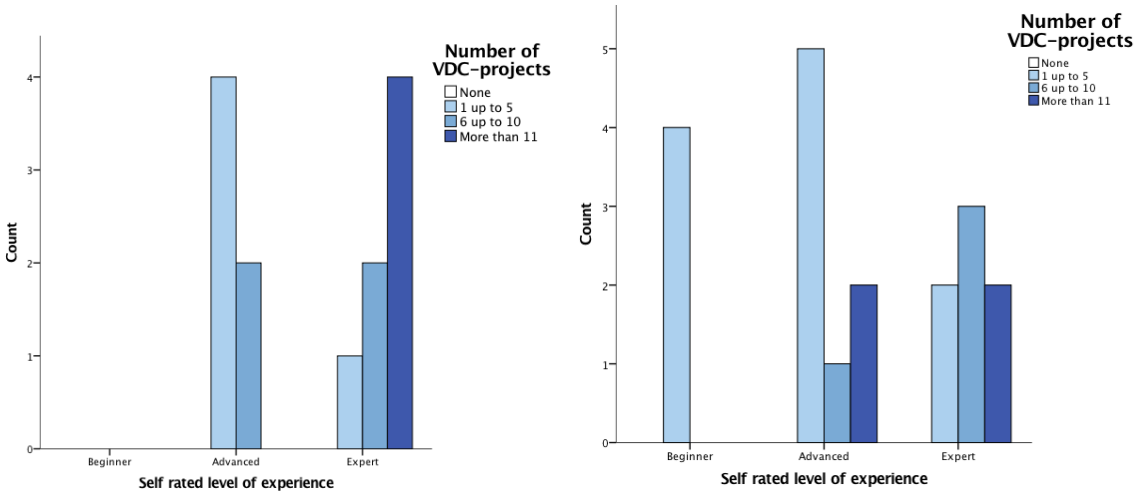


Figure 23: Self rated level of experience per number of VDC-projects performed (left: Buildings and right: Transport & Planning).

### 7.1.4 Reponses per statements

As mentioned in the methodology chapter the values derived from the statements are on an ordinal scale. So, to determine the general attitude of the respondents regarding a particular statement one must assess the median. In addition, looking at the minimum/maximum value, quartiles, Skewness, and Kurtosis of the data per statement a more in-depth perspective is created on the variance of the data per statement. In table 5 the previously mentioned measurement characteristics are presented.

| | | C1 | | C2 | | | | C3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q3: T&P-projects more stakeholders than BL | Q6: Added value of VDC in a Project | Q7: Preparation is essential | Q8: Preparation with internal stakeholders | Q9: Internal stakeholders trained | Q10: External stakeholders trained | Q11: Two or more stakeholders | Q12: Shared space | Q13: Time | Q14: Common objective | Q15: Focus on objective | Q16: Common language | Q17: Knowledge in area of objective | Q18: Interaction |
| N | Valid | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| | Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Median | | 3 | 4 | 5 | 3 | 4 | 2 | 3 | 4 | 2 | 4 | 4 | 4 | 4 | 4 |
| Minimum | | 1 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| Maximum | | 5 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 |
| Percentiles | 25 | 3.00 | 4.00 | 4.00 | 2.00 | 2.00 | 2.00 | 3.00 | 3.00 | 1.00 | 4.00 | 3.25 | 3.00 | 3.00 | 3.00 |
| | 50 | 3.00 | 4.00 | 5.00 | 3.00 | 4.00 | 2.00 | 3.00 | 4.00 | 2.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| | 75 | 4.00 | 5.00 | 5.00 | 4.00 | 4.00 | 3.00 | 4.00 | 4.00 | 3.00 | 5.00 | 4.75 | 4.75 | 4.00 | 4.00 |
| Skewness | | -0.384 | -1.020 | -1.022 | -0.065 | -0.302 | 0.170 | -0.606 | -1.203 | -0.060 | -1.286 | -1.032 | -0.847 | -0.771 | -0.134 |
| Std. Error of Skewness | | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 | 0.414 |
| Kurtosis | | 0.170 | 2.757 | -1.025 | -0.935 | -1.099 | -0.627 | 0.023 | 1.486 | -1.517 | 1.264 | 0.906 | 1.687 | -0.017 | -0.893 |
| Std. Error of Kurtosis | | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 | 0.809 |

Table 5: Descriptive analysis of the statements.

In figure 24 the median and the data distribution of the statements is visualized. The symbols represent the median of a statement and the line the distribution of the respondents.

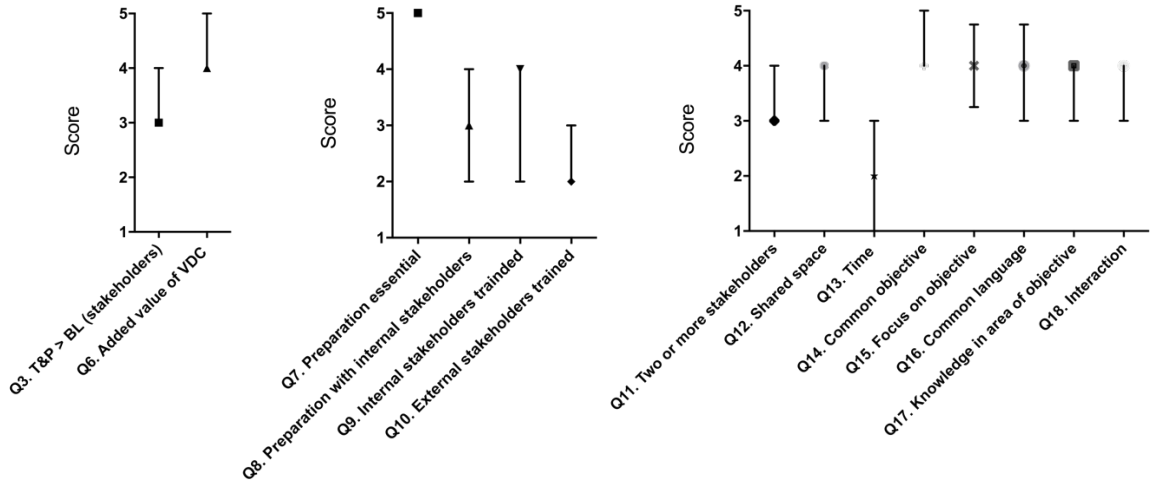


Figure 24: Attitude of respondents regarding statements C1 (left), C2 (middle), and C3 (right).

As discussed in the research methodology a statement with a median of 4 or higher can be considered valid and 3 or lower as invalid. On the basis of these boundary conditions table 6 is formulated stating the general opinion of the respondents per question.

| | | Topic | Outcome (Median) | Outcome (Meaning) |
|---|---|---|---|---|
| C1 | Q3 | Transport and planning projects have more stakeholders than building projects | 3 | Neutral |
| | Q6 | Added value of VDC in a project | 4 | Big |
| C2 | Q7 | Preparation is essential | 5 | Totally agree |
| | Q8 | Preparation with all internal stakeholders | 3 | Neutral |
| | Q9 | Internal stakeholders trained with VDC | 4 | Agree |
| | Q10 | External stakeholders trained with VDC | 2 | Disagree |
| C3 | Q11 | Two or more stakeholders | 3 | Neutral |
| | Q12 | Shared space | 4 | Agree |
| | Q13 | No time no collaboration | 2 | Disagree |
| | Q14 | Common objective | 4 | Agree |
| | Q15 | Focus on objective | 4 | Agree |
| | Q16 | Common language | 4 | Agree |
| | Q17 | Knowledge in area of objective | 4 | Agree |
| | Q18 | Interaction | 4 | Agree |

Table 6: General attitude of respondents for each question or statement.

## 7.2 Results: Nonparametric analysis

### 7.2.1 Representativeness of sample

In order to determine if the sample can be considered a valid representation of the actual population (i.e. goodness-for-fit) a chi-square test will be performed. The Null-hypothesis for this test is: *the sample's distribution is similar to the distribution of the population.* In table 7 and 8 the results of the chi-squared test are presented. As can be seen in table 7 the chi-square is 0.002 with a significance of 0.967 meaning that the Null-hypotheses is retained *(Asymp. Sig. > 0.05).* In order words, it can ben concluded that the sample taken can be considered as a valid representation of the overall population of VDC-experts at RHDHV.

| | Population N | Observed N | Expected N | Residual |
|---|---|---|---|---|
| Buildings | 15 | 14 | 14.1 | -0.1 |
| Transport & Planning | 19 | 18 | 17.9 | 0.1 |
| Total | 34 | 32 | | |

Table 7: Frequency data chi-square test

| | **Chi-square Test** (goodness-for-fit) |
|---|---|
| Chi-Square | .002[a] |
| df | 1 |
| Asymp. Sig. | 0.967 |

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 14.1.

Table 8: Test statistics chi-square test

### 7.2.2 Correlation between business lines and answers

In order to determine if the attitude towards each statement are similar across the two business lines a two independent sample test (i.e. Mann-Whitney test) will be performed. The Null-hypothesis for this test is: *The distribution of the answers provided on question (N) are the same across the two business lines* (N= number of the question). In table 9 the results are presented. As can be seen the hypothesis is only rejected for Q3 and Q6 (*Asymp. Sig. < 0.05)*. For the other question the hypothesis is retained.

**Hypothesis:** *Distribution of Qn is the same across categories of Q2*

| | Qn | Significance | Decision |
|---|---|---|---|
| C1 | **Q3** | **0.003[1]** | **Reject** |
| | Q4 | 0.180[1] | *Retain* |
| | Q5 | 0.301[1] | *Retain* |
| | **Q6** | **0.008[1]** | **Reject** |
| C2 | Q7 | 1.000[1] | *Retain* |
| | Q8 | 0.866[1] | *Retain* |
| | Q9 | 0.077[1] | *Retain* |
| | Q10 | 0.667[1] | *Retain* |
| C3 | Q11 | 0.442[1] | Retain |
| | Q12 | 0.180[1] | *Retain* |
| | Q13 | 0.536[1] | *Retain* |
| | Q14 | 0.808[1] | *Retain* |
| | Q15 | 0.639[1] | *Retain* |
| | Q16 | 0.319[1] | *Retain* |
| | Q17 | 0.667[1] | *Retain* |
| | Q18 | 0.448[1] | *Retain* |

Asymptotic significances are displayed. The significance level is 0.05

[1] Exact significance is displayed for this test

Table 9: Results Mann-Whitney test.

In table 10 the distribution characteristics of Q3 and Q6 are plotted against the two business lines. This is done to gain better understanding of two rejected hypotheses. As can be seen for Q3, which is also visualised in figure 23, the data of Transport and Planning has a median of 4 with minimum value of 3 (i.e. downwards outliers). Therefore, the business line as group agrees with the statement. On the other hand, the data of Buildings for Q3 has a more even distribution. With a median of 3, minimum and maximum value of 1 and 4, and skewness of -0.074 (i.e. skewed to the left) it can be stated that although the median indicates a neutral opinion the general group opinion tends towards disagree. Meaning that the two business lines have a different perspective on the statement that: *Transport & Planning projects are characterized by more stakeholders than Building projects.*

| | | Q3 | | Q6 | |
|---|---|---|---|---|---|
| | | Buildings | Transport & Planning | Buildings | Transport & Planning |
| N | Valid | 14 | 18 | 14 | 18 |
| | Missing | 0 | 0 | 0 | 0 |
| Median | | 3 | 4 | 4 | 5 |
| Minimum | | 1 | 3 | 2 | 4 |
| Maximum | | 4 | 5 | 5 | 5 |
| Percentiles | 25 | 2.00 | 3.00 | 4.00 | 4.00 |
| | 50 | 3.00 | 4.00 | 4.00 | 5.00 |
| | 75 | 3.00 | 4.00 | 4.00 | 5.00 |
| Skewness | | -0.074 | 0.408 | -1.697 | -0.244 |
| Std. Error of Skewness | | 0.597 | 0.536 | 0.597 | 0.536 |
| Kurtosis | | -0.182 | -0.513 | 5.119 | -2.199 |
| Std. Error of Kurtosis | | 1.154 | 1.038 | 1.154 | 1.038 |

Table 10: Data distribution characteristics of Q3 and Q6.

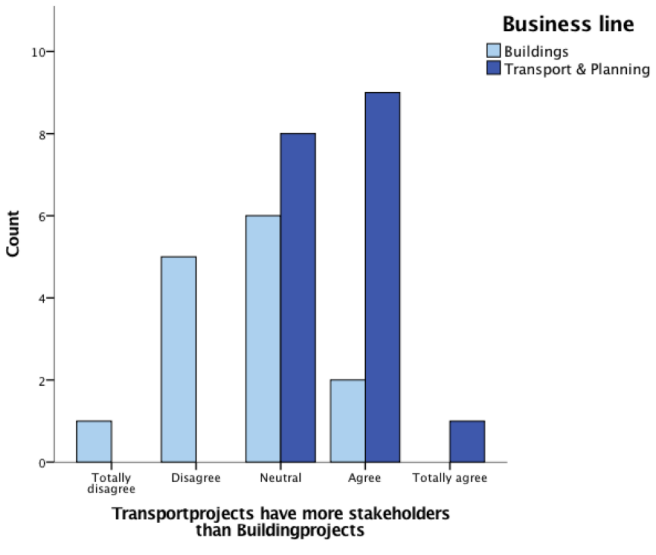


Figure 25: Count per Likert-category for Q3 visualized.

Likewise, for Q6 (visualised in paragraph 7.1.3 - figure 22(right)) it can be stated that both business lines rate the added value of VDC in a project as big to very big. However, the data of Buildings is with a minimum and maximum value of 2 and 5 more distributed than that of Transport and Planning with a minimum and maximum value of 4 and 5. Meaning that the respondents of Buildings are less ambiguous in comparison with the respondents of Transport and Planning with regard to added value of VDC in a project.

### 7.2.3 Correlation between experience and answers

In order to determine if there is a correlation between the number of VDC-projects performed by a respondent and the answers provided a test for two or more independent samples will be conducted (i.e. Kruskal-wallis test). The Null-hypothesis for this test is: *the number of VDC-projects performed has no influence on the answers provided*. The results are presented in table 11(left). As can be seen, with one exception Q5, the Null hypothesis is retained for all questions (*Asymp. Sig. > 0.05)*.

Furthermore, a similar test was performed to determine if there is any correlation between the self rated level of experience and answers provided by a respondent. The Null-hypothesis for this test is: *the self rated level of experience has no influence on the answers provided.* As can be seen in table 11(right), with one exception of Q4, the Null hypothesis is retained for all questions (*Asymp. Sig. > 0.05)*.

The fact that the hypotheses of Q4 and Q5 are rejected is not strange because the amount of projects performed with VDC is in someway correlated with the self rated level of experience.

This is because a respondent who rates him or her self as beginner will most likely not have performed 11 or more project with VDC. To conclude, self-rated experience or experience on number of VDC-projects performed has no influence on the answers given by the respondents.

**Hypothesis:** *Distribution of Qn is the same across categories of Q4*

| | Qn | Significance | Decision |
|---|---|---|---|
| C1 | Q3 | 0.133 | *Retain* |
| | **Q5** | **0.009** | **Reject** |
| | Q6 | 0.931 | *Retain* |
| | Q7 | 0.280 | *Retain* |
| C2 | Q8 | 0.328 | *Retain* |
| | Q9 | 0.490 | *Retain* |
| | Q10 | 0.169 | *Retain* |
| | Q11 | 0.431 | *Retain* |
| C3 | Q12 | 0.506 | *Retain* |
| | Q13 | 0.558 | *Retain* |
| | Q14 | 0.228 | *Retain* |
| | Q15 | 0.579 | *Retain* |
| | Q16 | 0.943 | *Retain* |
| | Q17 | 0.412 | *Retain* |
| | Q18 | 0.973 | *Retain* |

Asymptotic significances are displayed. The significance level is 0.05

**Hypothesis:** *Distribution of Qn is the same across categories of Q5*

| | Qn | Significance | Decision |
|---|---|---|---|
| C1 | Q3 | 0.729 | *Retain* |
| | **Q4** | **0.010** | **Reject** |
| | Q6 | 0.980 | *Retain* |
| | Q7 | 0.989 | *Retain* |
| C2 | Q8 | 0.620 | *Retain* |
| | Q9 | 0.255 | *Retain* |
| | Q10 | 0.646 | *Retain* |
| | Q11 | 0.710 | *Retain* |
| C3 | Q12 | 0.391 | *Retain* |
| | Q13 | 0.504 | *Retain* |
| | Q14 | 0.543 | *Retain* |
| | Q15 | 0.934 | *Retain* |
| | Q16 | 0.971 | *Retain* |
| | Q17 | 0.310 | *Retain* |
| | Q18 | 0.707 | *Retain* |

Asymptotic significances are displayed. The significance level is 0.05

Table 11: Results Kruskal-Wallis test across cat. Q4 (left) and Results Kruskal-Wallis test across cat. Q5 (right).

## 7.3 Results: Feedback

At the end of the questionnaire the opportunity was presented by means of an open-question to provide feedback or other suggestions. Out of the thirty respondents nine respondent used this opportunity. Five of these comments were related to aspects of preparation and collaboration and four to the questionnaire it-self.

### 7.3.1 Aspects of preparation and collaboration

In table 12 an enumerated overview is presented of the addressed aspects. The comments provided by R1, R5, and R14 indicated three new aspects which are not covered by the road map for constructive collaboration; group size during preparation, form of preparation depends on session objective, and all session participants must be prepared by the facilitator of the session. R14, R18 and R23 on the other hand confirmed several aspects of the road map. These aspects are stakeholder identification, classification of roles and responsibilities, and sharing interests.

| Respondent | Comment | Essence of comment |
|---|---|---|
| **R1** | Preparation of a VDC-session is better to do in a small group because otherwise you will do a session before a session. | *Preparation in small group* |
| **R5** | The form of preparation depends on the objective of your session. A brainstorm session requires a different form of preparation then a design session. | *Preparation depends on session objective* |
| **R14** | Essential to preparation is to know who needs to be involved. So a stakeholder selection needs to be made. If this is done incorrectly a session is practically useless. Furthermore, all participants need to be prepared by the session facilitator | *Stakeholder selection*<br>*Participants need to be prepared by facilitator* |
| **R18** | A stakeholder analyses to determine roles and responsibilities is essential in the preparation. | *Stakeholder analyses*<br>*Roles*<br>*Responsibilities.* |
| **R23** | An important aspect to enhance collaboration is sharing each other's interest and why this is so important to them. | *Sharing interests* |

Table 12: Comments regarding aspects of preparation and collaboration.

### 7.3.2 Questionnaire

In addition to the comments related to the content of the questionnaire, four respondents made some remarks about the format of the questionnaire. R2 and R14 had some difficulties with the black and white perspective of the statements. However, as was mentioned in the research methodology the statements were intentionally formulated in a black and white perspective. Furthermore, R7 indicated that there might be a difference in perception of what a VDC-session might be. Lastly, R27 mentioned that the VDC method was put in a negative perspective in Q10 and this is not in line with the general idea of VDC.

| Respondent | Comment | Essence of comment |
|---|---|---|
| **R2** | The statements are black and white. However, the VDC methodology is more nuanced. | *Black and white perspective* |
| **R7** | Possibility that respondents have a different interpretation of what a VDC-session is. | *Interpretation of a VDC-session* |
| **R14** | Urge to provide commentary on provide answers. | *Black and white perspective* |
| **R27** | 'Entrusting/burdening of external stakeholders with VDC' sounds to negative. VDC is meant as a relief for stakeholders. | *Bad choice of word* |

Table 13: Comments regarding questionnaire format.

# 8 Discussion

In the introduction of this research, the question was raised in what way it would be possible to develop constructive collaboration among stakeholders to improve decision-making in a VDC engineering design project. Based on a theoretical and practical study, a road map for developing constructive collaboration among stakeholders in the run-up to a VDC engineering design project was formulated. This road map however included multiple assumptions. Therefore, in order to validate these assumptions, a questionnaire was conducted. The findings of the questionnaire were presented in the previous chapter and will be discussed below.

## 8.1 Discussion of findings

**Similar perception VDC-experts**

Although the researcher had expected a difference in the perception of Building and Transport & Planning VDC-experts and between less and more experienced VDC-experts on the statement categories of collaboration and preparation of a VDC-process. The findings did not indicate any difference. Although this different outcome, it presented the advantage that both business lines could be observed as one. What increased the validity of the proposed road map and showed that experience or sector does not influence the road map. Indicating possible generalizability of the road map to a different context. For example, a different business line of RHDHV.

**Preparation is essential for a VDC-process**

The literature study on the VDC methodology indicated that no formal methods and guidelines to structure a VDC-process are developed. This limitation was reflected in the application of VDC by RHDHV and resulted in a misalignment of expectations of stakeholders and information discussed during the VDC-processes of the observed projects. This misalignment consequently affected the decision-making process negatively. However, a remarkable aspect was that the VDC-experts as a group totally agreed upon the statement that preparation is essential to a successful VDC-process. This suggests a general sense of urgency among the VDC-experts for proper preparation, but it did not result in a more structured approach for preparing a VDC-process within the organisation.

**Who to involve during preparation of a VDC-process**

As seen during the literature study, one of the key aspects of VDC methodology is to increase multi-party collaboration in order to intensify the interaction between stakeholders and information. In addition, the first step of the road map for constructive collaboration states that the more stakeholders being involved in the process of identifying stakeholders will result in a more comprehensive list. However, the findings of the questionnaire suggest that not all internal stakeholders should be involved during the preparation, consequently also not during the process of identifying stakeholders. This is remarkable, because theoretically this would lead to a

decrease in multi-party collaboration and an increase in the chance of missing out key stakeholders during the decision-making process.

**Knowledge of the VDC methodology**

A VDC-process applies multi-disciplinary performance models and requires input from all attendees. The road map assumes that both internal and external stakeholders require training on the methodology when invited to participate in a VDC-process. For internal stakeholders, this research confirmed the assumption, but for the external stakeholders it was rejected. This is remarkable because the case study revealed that external stakeholders might cause disturbance to the decision-making process when not trained. Furthermore, previously it was discussed that not all internal stakeholders should be involved during the preparation. This could suggest that VDC-experts consider training and preparation as separate elements or that training as referred to in this research differs from training as referred to by VDC-experts.

**Ingredients for collaboration during preparation**

Based on the findings of this research, it can be stated that the aspects *shared space, time, common objective, focus on objective, common language, and knowledge in area of objective* are valid elements of collaboration during preparation of a VDC-process according to the VDC-experts. On the other hand, the aspect *people* was not confirmed in this research due to a neutral attitude of the VDC-experts. However, a closer examination revealed that due to skewness in data to the right, the neutral position tends more towards agreement than disagreement. In other words, this aspect is not ruled out. A possible explanation for this modest tendency towards the aspect *people* could be related to the perception of VDC-experts that not all internal stakeholders should be involved during the preparation. Furthermore, if the findings are assessed in more detail some additional remarks can be made to the different aspects.

Even though VDC-experts do not fully agree that preparation of a VDC-process must take place in collaboration with more than two stakeholders. They are convinced that collaboration between stakeholders itself cannot be neglected in case there is lack of time during preparation. This is contradictory because if preparation does not need to be performed by two or more stakeholders it is possible to neglect collaboration. This simply because there is no one to collaborate with. A possible explanation, based on the case study results, for this contradiction is that due to the absence of guidelines for structuring the preparation of VDC-process. VDC-experts are still preparing a VDC-process in (fragmented) traditional manner. In other words, without the involvement of other stakeholders.

Another remark that can be made is regarding the aspects *interaction, shared space*, and *common language.* The fact that the VDC-experts as a group mutually agreed upon the importance of those aspects could indicate that the VDC-experts are experiencing the urge to interact with stakeholders in one designated place which can be monitored and controlled prior to a VDC-process. In other words, collaborate either physical or virtual with other stakeholders.

Lastly, the first step in the proposed road map uses the issue at hand to identify other stakeholders in the preparation of a VDC-process. This suggested approach can be underpinned by the fact that VDC-experts are convinced that in order for a stakeholder to be relevant to the

process, the stakeholders must possess knowledge in the area of the objective of the VDC-process, have a shared objective with other stakeholders, and must be focussed on this shared objective. Furthermore, without presenting the road map as whole to the respondents of the questionnaire, during the open feedback three respondents confirmed that identification and classification based on roles of stakeholders is part of the preparation of a VDC-process and depends on the objective of the VDC-process to be prepared (i.e. issue at hand what needs to be solved).

## 8.2 Implications of the findings for the road map

The previously discussed findings did not provide evidence to believe that the proposed road map to develop constructive collaboration among stakeholders in the run-up to a VDC-process is invalid. However, two aspects of the road map were perceived as questionable by the VDC-experts. First, if all stakeholders should be involved in the preparation of a VDC-process and second, whether external stakeholders should be trained on VDC.

A potential implication of the first aspect could be that instead of involving all internal stakeholders during the preparation, only a small group of internal stakeholders will be involved. However, one has to make sure that the preparation of a VDC-process is not performed by one single stakeholder, because this contradicts with the core of VDC and increases the chance of overlooking stakeholders. The second aspect could imply that training of external stakeholders, as suggested by the road map, is not a feasible option. If the behaviour of external stakeholders during the decision-making process has to be influenced, it must be achieved in another way. A possible alternative relates to managing the expectations of external stakeholders. By managing their expectations carefully, they are provided with additional knowledge regards the VDC-process. This will reduce the chance of unexpected events.

In the above section, the two aspects were discussed separately. However, when assessing them critically and in the context of this research an overarching duality can be discovered. Who are exactly the relevant stakeholders to the process and to what extent should they be involved in order to have constructive collaboration.

# 9 Revision of the road map

The road map as developed in chapter 6 was created on the basis of elements gathered from two areas of expertise: stakeholder management and collaboration. However, the questionnaire has shown that by merging the two areas of expertise, no satisfactory road map able to structure the run-up to a VDC-process is provided. The question of *"Which stakeholders are relevant and to what extent are they required to be involved in the process?"* could not be answered. In order to provide an answer to this question, the knowledge area of process management will be assessed. The results of this assessment will support the development of a revisited version of the road map.

## 9.1 Why process management?

The reason for consulting the area of process management is twofold. First, in the introduction of this research it was mentioned that VDC originates from the shift from executing projects to managing projects. This transition is similar to the essence of process management, because instead of focussing on what should be changed it puts the focus on the way this change is achieved. (de Bruijn et al., 2010) Second, in the run-up to a VDC-session the focus is on engaging competent stakeholders, gathering information regarding the issue at hand, and drawing up the agenda of the session. Therefore, the road map in its current format shows many similarities with the activities for creating a process design (i.e. run-up) as defined by de Bruijn et al. (2010). These similarities will be discussed in more detail in paragraph 9.4.1.

## 9.2 What is process management?

Process management in the context of project management as described by de Bruijn et al. (2010) is focussed on change in complex issues and can be characterised by multiple actors who are dependent on each other and negotiate with each other in a series of meetings. In the act of setting up and guiding these meetings two roles exist. The first role is defined as process managers, mediators or facilitators. They are the ones who guide and organize the negotiated changes. Simply said, these changers leave the shaping of the content to others while they remain focussed on process-related aspects. (de Bruijn et al., 2010) Besides the role of process manager, the role of process architect, also known as initiator, exists. This person ensures that the process as designed is attractive to all involved actors. With attractive is meant that the process design should provide the actors with enough prospect to let them serve their own interest. (de Bruijn et al., 2010)

When developing a process design, a process architect must take the core elements of a good process into account. According to de Bruijn et al. (2010) these are: *openness, protection of core values, progress,* and *substance (i.e. content)*. For each of those core elements several design principles exist. A process architect can use these design principles to develop a well balanced process design. In addition, de Bruijn et al. (2010) have listed several activities which can be

performed in the process of designing a process design. In the following sections the core elements of a good process design with their corresponding design principles (paragraph 9.2.1) and process design activities (paragraph 9.2.2) will be discussed in more detail.

### 9.2.1 Core elements of a process design

In figure 26, the four core elements of a good process are visualised however a more elaborated explanation will be provided below.

In order to have a good process, the initiator first has to make sure that the process has an open character - *Openness*. An open process refers to the degree to which stakeholders can influence the draw up of the agenda and decision-making process. Related to openness is the risk that if too many stakeholders are involved in the process this might result in utter indecision (i.e. uncontrollable decision-making without any progress). Secondly, the initiator has to make sure that the core values of the participants are protected and will not be harmed by the outcome of the process - *Protection of core values*. The reason for this is that in an open process stakeholders need to take a leap of faith in the process so that they eventually can come to a shared solution, or in other words, they need to invest to be able to gain from the process. However, by taking this leap of faith they also take the risk that their interest might not be addressed sufficiently. This means that they could also lose by participating in the process. Thirdly, *Progress* is of great importance. Without proper incentives to generate momentum, the process could turn into a slow and inadequate process in which stakeholders only discuss and not decide. To avoid such a situation, progress must be ensured. Lastly, after the previous three core elements are taken into consideration, the risk still exists that the process has drifted away from its initial objective and that the outcome of the process is not feasible and/or does not deliver the desired results. Therefore, the initiator has to make sure that the process delivers substance which is of a certain quality standard.


Figure 26: The four core-elements of a process design. (de Bruijn et al., 2010, p. 42)

### 9.2.2 Design principles

As discussed, per core element several design principles exist. These design principles act as guidelines for establishing process agreements. Process agreements are made prior to a process

and define the rules of the game. In other words, by which ground rules will the participating parties collaborate and make decisions regarding the issue(s) at hand. In the table 14 the design principles per core element are presented in an enumerated overview.

| |
|---|
| **Openness** |
| • All relevant parties are involved in the decision-making process<br>• Substantive choices are transformed into process-type agreements<br>• Both process and process management are transparent |
| **Protection of core values** |
| • The core values of parties are protected<br>• Parties commit to the process rather than the result<br>• Parties may postpone their commitments<br>• The process has exit rules |
| **Progress** |
| • Stimulate early participation<br>• The process carries a prospect of gain<br>• There are quick wins<br>• The process is heavily staffed<br>• Conflicts are addressed in the periphery of the process<br>• Tolerance towards ambiguity<br>• Command and control are used to maintain momentum |
| **Substance** |
| • Substantive insights are used for facilitation. The roles of experts and stakeholders are both bundled and unbundled<br>• The process proceeds from substantive variety to selection |

Table 14: Design principles. (de Bruijn et al., 2010, p. 43)

## 9.3 Activities for creating a process design

In the previous paragraphs, it was mentioned that the core elements and design principles of a good process will assist the initiator with defining the ground rules prior to the process. However, the question of how this run-up to the process exactly looks like and what kind of activities must be performed to make those process agreements was not answered. Therefore, in this paragraph the activities as proposed by de Bruijn et al. (2010) will be discussed. However, before this will be done the preconditions for a successful process approach will be explained.

### 9.3.1 Preconditions

For the success of a process design two preconditions exists. First, the process design must be appealing to all parties involved and should provide them with enough opportunities to influence the decision-making process while keeping their core values protected. (de Bruijn et al., 2010) In order to achieve this, parties must have an influence in shaping the process design. Therefore, the negotiations about the process agreements shaping the process design, must be treated like a process itself. A process prior to a process sounds inefficient and counterproductive, but it has several advantages. It will generate shared ownership of the process design, because parties will learn about the issue(s) that will be discussed during the process and it will let parties realize that process agreements are needed in order to have a successful decision-making process. The second precondition is related to fact that there must be a sense of urgency among the participating parties, otherwise there will be no incentive to collaborate. (Kotter, 1996) In case of

a process design, the sense of urgency can be split up into two components: a substantive component and process-oriented component. (de Bruijn et al., 2010) The first component implies that participants must be convinced that there is an issue that needs to be solved and second that this issue cannot be solved unilateral and therefore collaboration is needed.

### 9.3.2 Process design activities explained

In order to develop a process design, a process architect has to preform several activities. The set of activities as recommended by de Bruijn et al. (2010) for creating a good process design is shown in figure 27. Although this set of activities looks static, it must be mentioned that they are subject to some flexibility. The reason for this is that the number and order of the activities are dependent on the substantive complexity and the nature of conflicts and interest. (de Bruijn et al., 2010) The eventual composition of a particular case will be determined by the process architect. To be able to make such decisions a process architect must have a sense of managerial creativity and sensitivity. In order words, without a competent process architect the possibility of failure will still exist even if a process architect has gone through all the activities correctly.

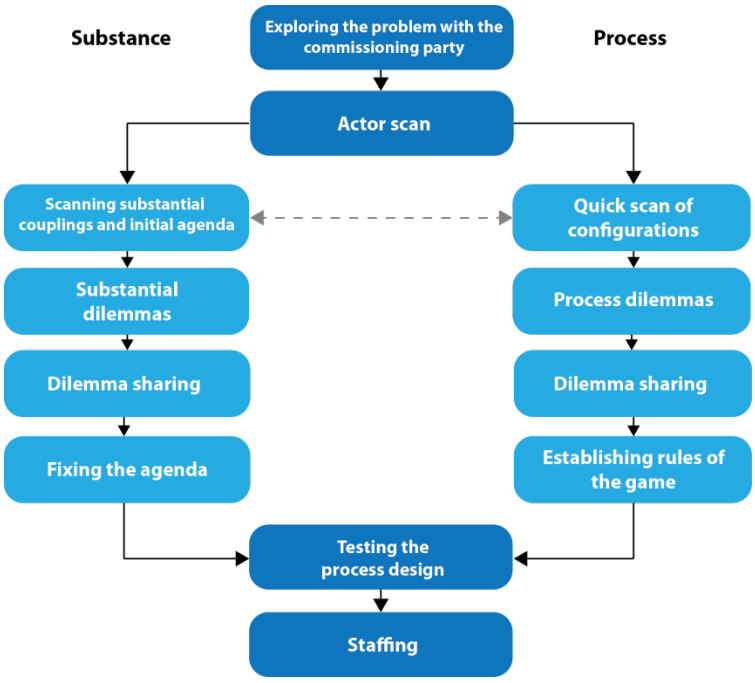


Figure 27: Activities for creating a process design. (de Bruijn et al., 2010, p. 64)

**Exploring the problem with the commissioning party**

The first activity in creating a process design is to explore the problem as process architect in collaboration with the commissioning party. The commissioning party consists out of the initiator or initiators of the project. The result of this first exploration with the commissioning party will be an initial list of relevant actors and a feeling of the sense of urgency among actors regarding the matter. In case the sense of urgency appears to be low among actors, actions are required to increase the sense of urgency. Lastly, it must be mentioned that because not all relevant actors are invited during this first problem exploration the result tends to be rather biased.

**Actor scan**

During the second activity, a preliminary scan will be conducted by the commissioning party on the actors as listed by the previous activity. The purpose of this scan is to gather relevant information about the actors with respect to their views, interest, cores values, opportunities and risks, and incentives and disincentives. Based on the result, the process architect will either decide to involve or not to involve other actors in subsequent scanning rounds.

**Scanning substantive couplings and the initial agenda** (substantive)

With the information acquired by the actor scan and the quick scan configurations, the process architect will have a clear picture of the issues at play. With this the process architect will be able to look for potential substantive couplings between issues. By coupling several issues, a process design can be made more appealing to actors. In other words, by coupling issues, collaboration between actors is stimulated. Based on these substantive couplings, an initial agenda will be formulated.

**Substantial dilemmas[11], Dilemma sharing, and Fixing the agenda** (substantive)

After the initial agenda is set up, the process architect will determine in what way the different dilemmas are related to each other. This is important because the outcome of one dilemma might have an influence on another. On the basis of these relationships, a classification of the substantive dilemmas will be made. This classification will act as the substantive agenda of the process and can either be in the form of a decision tree or dilemma groups. The advantage of grouping dilemmas is that it allows package deals to be made.

**Quick scan of configurations** (process)

With the information acquired by the actor scan, the process architect can make an overview in which interaction patterns of actors are visualized. This analysis on group dynamics will reveal who has a key position, either socially or substantively, in the process and who has a relative marginal role.

**Process dilemmas, Dilemma sharing, and Establishing rules of the game** (process)

In formulating process agreements (i.e. rules of the game) a process architect first has to overcome several process dilemmas. Take for example the dilemma of how many parties will be involved in the process. If all actors are involved, the risk of a slow and tedious process may occur. However, on the other hand if only a few actors are involved the support for the process outcome may be small. Another example of a process dilemma relates to the tempo of the process, should it be at a slow or fast pace. A slow process, in comparison to a fast process, will be more accurate, however it will also cost a lot more time and effort.

[11] A dilemma is an issue to which there is more than one possible solutions. Each of those solutions has its pros and cons. (Van Twist, Edelenbos, & van der Broek, 1998)

After these process related dilemmas are settled, the rules of the game will be established. This will be done with support of the process design principles. The rules of the game can be divided into four categories: Entry and Exit rules, Decision-making rules, Organic rules (i.e. rules that define the organisation of the process), and Rules about planning and budget.

**Testing the process design**

In order to discover bugs and flaws in a process design, which are potential threats to the success of a process, the opportunity exists to test the process design. Testing the process design can especially be beneficial in case the process has only one opportunity to be successful.

**Staffing**

In the last step of creating a process design, the actual people who will participate in the process will be chosen. It is important that the people that will participate in the process are competent, of sufficient rank of file, and able to act on behalf of the people or the organisation that they represent.

## 9.4 Comparison of road map with activities of de Bruijn & ten Heuvelhof

In this section, the road map as developed in chapter 6 will be compared with the activities for creating a process design as defined by de Bruijn et al. (2010). The objective is to identify similarities between the two (paragraph 9.4.1) and opportunities to further improve the road map (paragraph 9.4.2).

### 9.4.1 Similarities

While comparing the two sets of activities, four similarities were found, see numbers 1 to 4 in figure 28. These four overlapping areas are elaborated below.

The first similarity was found between the activity ***Identify*** and the activities of ***Exploring the problem with the commissioning party*** **&** ***actor scan***. These activities show similarities due to the fact that in the identification step of the road map all internal stakeholders known at that point are involved in identifying other relevant actors. This process is similar to the activity of *Exploring the problem with the commissioning party*. Furthermore, *identify* activity of the road map has an iterative character, because the identification will be repeated, with additional stakeholders in every round, up to the point that there is a comprehensive list of stakeholders. This iterative character of identifying actors can also be found in the activity *actor scan.*

The second similarity was found between the activities ***Classify*** and ***Quick scan of configurations***. In both activities, a classification of stakeholders will be made. However, the difference between the two is that the road map makes a differentiation between stakeholders on the basis of their role in a project and de Bruijn & ten Heuvelhof make this classification upon their position in the group.

A third similarity was found between the activity of ***Collaborate*** and ***Establishing rules of the game***. Both activities produce and prescribe ground rules for the actual decision-making process. However, the rules of the game of de Bruijn & ten Heuvelhof are more focused on the process related rules of collaboration, such as entry and exit rules, and the activity of *collaborate* as part of the road map are more focussed on the ground rules regarding the actual collaboration, such as location and medium used to communicate.

The fourth and last similarity was found between the activities ***Engage*** and ***Staffing***. In these activities stakeholders will be approached in order to get them involved in the process. The difference between the two activities is that *engage* as part of the road map advises to complete this activity prior to the establishment of the ground rules and de Bruijn & ten Heuvelhof recommend to do this after the process agreements have been made. An explanation for this difference is related to the fact that the activities as presented by Bruijn & ten Heuvelhof are based on other process designs, which were made for issues ranging from urban development issues to political issues. In those processes the chance is higher that the people who design the process will differ from the people who will be involved in the decision-making process. For example, the secretary of a CEO will be involved in the process design, however the CEO itself will participate during the decision-making process. The reason for this is that designing a process can be time consuming and that the secretary probably will not have the right decision-making power to participate in the decision-making process.

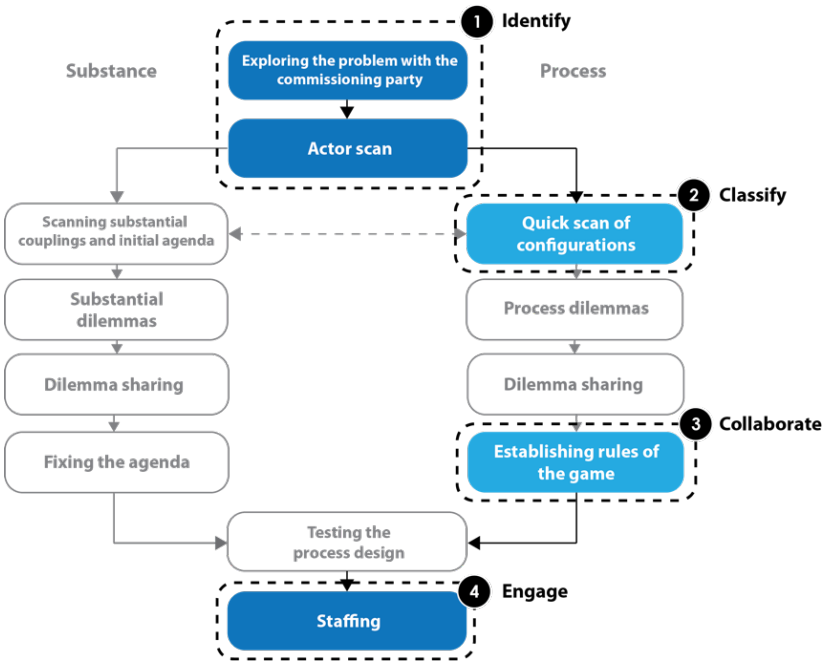


Figure 28: Similarities between the road map (black text) and the activities for creating a process design of de Bruijn et al. (2010).

### 9.4.2 Potential for improving the road map

The comparison has identified three aspects, see figure 29, by which the set of activities of de Bruijn & ten Heuvelhof support the road map, overcoming its limitation as indicated by the results of the questionnaire.

The road map in its current form only focusses on getting people involved and collaborate with each other during the process. As a result, the substance of the process is left out of scope when designing a process. This is different to the activities of de Bruijn & ten Heuvelhof, because they state: *"The process that is developed under guidance of a process manager must be sufficiently substantive. After all, a process without substance is empty."* (de Bruijn et al., 2010, p. 145) Meaning that although a process approach presents opportunities to solve a complex issue, the actual matter with respect to the issue (i.e. substance) cannot be neglected. This difference presents room for improvement. By integrating substantive activities into the road map, the participants of a VDC process will interact and get familiar with the substantive part of the issue in an earlier stage. Besides it is beneficial to the success of the run-up itself it, the early interaction between stakeholders will also contribute to separation of the Forming and Stroming phase from the VDC-process.

Furthermore, the four core elements of a process and design principles of a process as defined by De Bruijn & ten Heuvelhof provide a second opportunity to further improve the road map. Instead of solely prescribing ground rules on how to collaborate, as done by the road map, process agreements (or process rules) can assist in tackling process related issues such as many versus few stakeholders, what to do with a conflict between stakeholders during a process, and to what extent parties should be informed.

Lastly, prior to the start of an actual decision-making process, de Bruijn & ten Heuvelhof advise to, first test the process design if necessary. This activity could be an optional addition to the road map. However, testing would only be beneficial to processes in which failure of the process design would be catastrophic, meaning the process could turn into a situation that cannot be repaired.

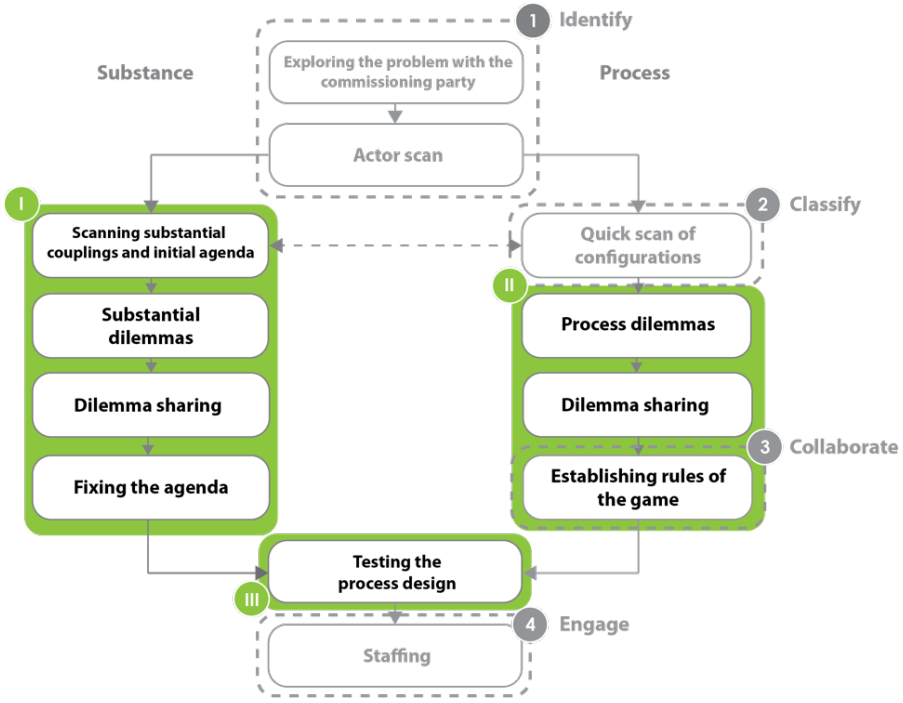


Figure 29: Identification of opportunities which can improve the road map.

## 9.5 Revisited version of the road map

In the revisited version of the road map, see figure 30, the four core elements as defined by de Bruijn et al. (2010) are taken into account and combined with the existing activities of the road map. The result of this is that the revisited road map, instead of solely focussing on the involvement and preparation of stakeholders, also focusses on the substantive side of the project. The benefit of combining both process and substance in the road map is that stakeholders will get familiar with both the group dynamics and the substance of the project in an earlier stage of the project. This will support the group of stakeholders in moving through the phases of Forming and Storming prior the actual decision-making process. Additionally, the fact that stakeholders that are part of the decision-making process will also participate in designing the process. This will develop a sense of ownership of the process (i.e. commitment to the process). Another more practical benefit of the revisited version of the road map is that it is visualised in a decision-tree manner. As a result, VDC-experts can directly adopt the road map in case they are preparing a VDC-process. But above all, the most important benefit of the road map in its new format is that it will allow VDC-experts to answer the question of *"Which stakeholders are relevant and to what extent are they required to be involved in the process?"* in stepwise manner.

Nonetheless, some comments must be made to place the revisited version of the road map into perspective. First, it must be mentioned that the road map is more dynamic than suggested in the figure. Due to the fact that every project is different, the importance and order in which the activities are presented will most likely differ between different cases. Therefore, a VDC-expert has to adopt a critical mind set when applying this road map to structure the run-up to a VDC-process. Second, it must be mentioned that although the revisited road map was discussed with an expert specialized in organisational changes multiple times during the development, it was not validated by the VDC-experts.

### 9.5.1 The road map explained

The road map will start with exploring the problem with the commissioning party. After that, other relevant parties will be involved to further identify actors. The result of these activities is a list with issues and relevant actors. The list of issues will be used to formulate a substantive agenda for the process and the list of relevant actors will be used to establish the rules of the game (i.e. process agreements). However, before process agreements are made, all actors will be classified on the basis of their role in the project. Hereafter, an iterative process will start. Stakeholders will be assessed one by one in order to decide whether they should participate in the process. The stakeholders that are invited to the dialogue will enter the negotiations to establishes the rules of the game. When both the rules of the game and the agenda are formulated, the process design will be evaluated on the eight aspects of collaboration. This evaluation can be seen as a kind of pre-flight check. If the process design complies on all eight aspects the choice can either be made to enter the decision-making arena or to first test the process design in test setting. However, it must be mentioned that this can be a time consuming and costly activity. When the test has been successful or it is decided that the test does not have to be performed, the actual process start.

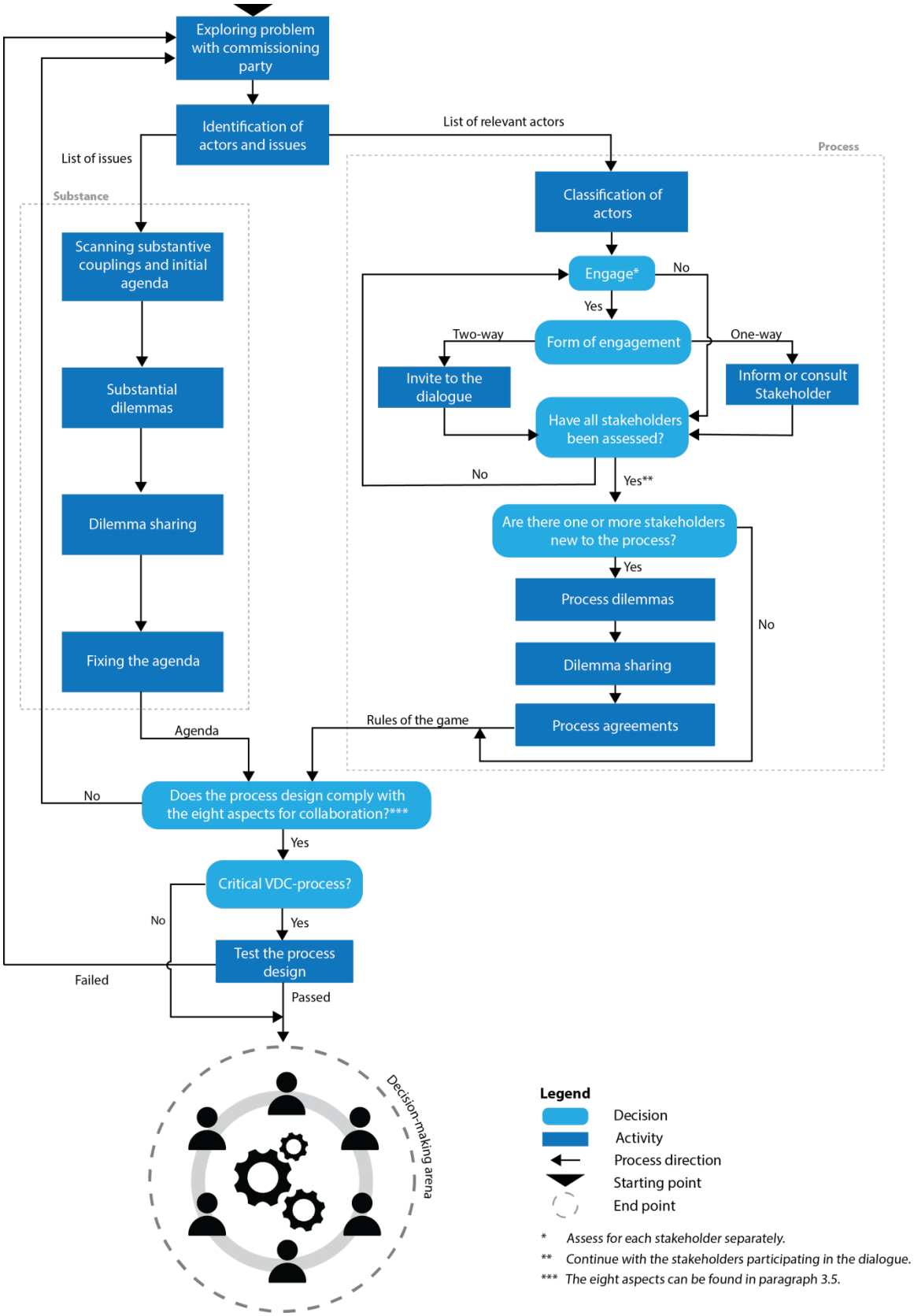


Figure 30: Revisited version of the road map.

## 9.6 Conclusion

In the previous chapter, it was concluded that the road map could not provide a satisfactory answer to the question: "*Which stakeholders are relevant and to what extent are they required to be involved in the process?*". Therefore, this chapter was aimed at making a revisited version of the road map which is able to answer this question. In order to make this revision, the area of process management was studied and compared with the existing road map. From this comparison several possibilities were identified to improve the road map. By combining these potential improvements with the existing activities included in the road map, a new version of the road map was created. The new version of the road map is focussed on both the substantive and process related aspects during the run-up to a VDC-process. The benefits of this approach are that stakeholders will start to interact with each other in an early stage and will get familiar in the run-up to a VDC-process with both the group dynamics and the substance of the project. This will provide the group of stakeholders with the opportunity to have passed the phases of Forming and Storming prior to the decision-making process. In the end, this will be beneficial to the actual VDC-process, because it can focus completely on the task for which it was developed; improving the quality of the decision-making.

# 10 Conclusion

Although VDC enables engineering organisations to improve the decision-making quality in projects, the fact that the run-up to a VDC-process has remained unstructured and constructive collaboration between stakeholders has a direct effect on the decision-making quality presents room for improvement. For that reason, this research was aimed at improving the decision-making process by developing a road map for creating constructive collaboration among stakeholders in the run-up to a VDC-process. Hence, the following research question was developed: "*In what way can constructive collaboration be developed in the run-up to a Virtual Design and Construction engineering design project to improve the decision-making process?".*

Before a structured answer could be given, the researcher discovered there were various definitions on what VDC exactly is. These definitions range from a technical perception in which BIM is seen as VDC, to an organisational perception in which VDC is seen as a process accelerator. In order to clear the area, some consensus on what is referred to as VDC was required. VDC as developed by Kunz and Fischer (2012) can be seen as a framework consisting of multi-disciplinary performance models in order to increase multi-party collaboration, reduce response latency between stakeholders, and manage an engineering design project effectively based on the product to be build, organisation that performs the design, and the process that an organisation follows to perform the design. These elements combined have the overall objective to improve the decision-making quality of projects and thereby to decrease change costs and lead time of projects.

After having reached consensus about the definition of VDC, the application of VDC by RHDHV could be observed. For this examination two case studies were performed and revealed that the VDC-experts leading those projects conducted the run-up mainly on the basis of their own experience. Although these VDC-experts had a lot of experience and knowhow they still showed signs of being human, such as overestimating and forgetting things. Their unstructured approach led to overlooking stakeholders and information; misalignment in expectations and information discussed; and unexpected behaviour of external stakeholders during a VDC-process. All these issues negatively affect the decision-making quality in one way or another. Therefore, assisting them in channelling their thoughts while preparing for a VDC-process by means of a road map could stimulate them to stay sharp and adopt a critical attitude. This will reduce the chance negative events will occur.

The question that can now be raised is what kind of activities a VDC-expert should perform during the run-up to a VDC-process. When looking at the issues indicated as part of the case study, these activities should ideally involve the identification of stakeholders and information, reducing misinterpretation between stakeholders, and managing the expectations of stakeholders prior to the process. However, the activities mentioned are based on the outcome of the case study and only relate to things that negatively affected decision-making quality. Most

likely, there are many more activities required to be performed prior to a VDC-process in order to make it successful.

In order to define these activities (i.e. stepping stones) a literature study was conducted. This study revealed that in order to develop constructive collaboration among a group of stakeholders, four stepping stones can be formulated. The first step is focused on identifying relevant stakeholders that can contribute to solving the issue at hand. The relationship of *Power, Legitimacy,* and *Urgency* of a stakeholder regarding the issue at hand are used to identify the right stakeholders. After that, a classification of the identified stakeholders is needed, because not all stakeholders are relevant during all phases of a project. As a result, a two-level classification methodology is adopted. On the one hand, the classification of stakeholders is made based on whether it considers internal or external stakeholders. On the other hand, the classification of stakeholders is based on their role within the project. These roles include the role of a client, decision-maker, designer, and representative. Now that the stakeholders are classified, they must be engaged to participate in the process. In case the stakeholder is not engaged it will stay a unilateral approach. The engagement can either be performed in a one-way or two-way fashion. A one-way approach is merely focussed on receiving or providing another stakeholder with information (i.e. inform or consult the party). The two-way fashion is focussed on mutual exchange of information and discussion of this information in the form of a dialogue. After having stakeholders identified, classified, and engaged in the process, a final activity is suggested to determine whether the previous activities have successfully prepared the group of stakeholders to enter the decision-making process. This so-called pre-flight check will assess the run-up on eight aspects which are essential in order to achieve constructive collaboration. These aspects consist of *two or more people, shared space, time, common objective, focus on objective, common language, knowledge in the area of objective, and interaction*. All these activities combined resulted in the road map as shown in figure 31.

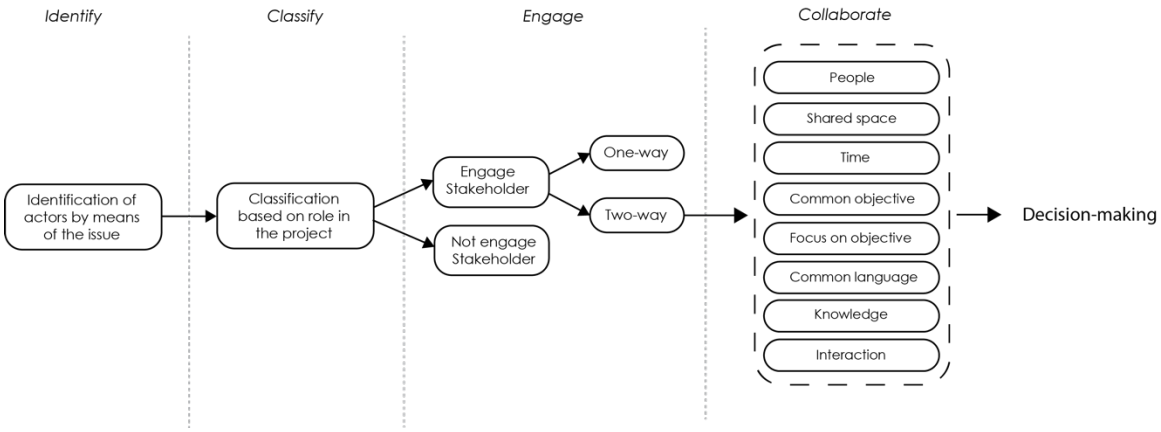


Figure 31: Initial version of the road map.

After having formulated a road map to structure the run-up to VDC-process, validation with the VDC experts was required in order to see whether they acknowledge the activities proposed in the road map. This validation was conducted by means of a questionnaire distributed among 32 VDC-experts of RHDHV. The results of the questionnaire did not provide evidence to believe that the activities proposed in the road map are invalid. However, it did indicate that an important duality was not resolved. This duality is related to the question: *"Which stakeholders are relevant*

*and to what extent are they required to be involved in the process?"*. Put differently, where do you draw the line and how do you draw this line with regards to the involvement and participation of a particular stakeholder in a project. The reason why no singular answer to this question exists is related to the fact that projects are largely dependent on their context, which means that every project is unique in one way or another. Therefore, a more dynamic approach is required to find an answer to the question.

In search for such a dynamic approach, the process management approach of de Bruijn et al. (2010) was assessed. Their approach focusses on the way change is achieved instead of being focussed on what should be changed only. Instead of providing a predetermined answer that should fit every situation, it provides guidance in finding an answer to that question. After making a comparison between the set of activities defined by de Bruijn & ten Heuvelhof and the road map, several opportunities to further improve the road map were identified.

The first improvement relates to the fact that de Bruijn & ten Heuvelhof deal with both the process and substantive side of a project prior to the decision-making whereas the road map was predominantly focussed on the process side. By integrating activities which structure the substance into the road map, participants of a VDC process will get familiar with the substantive part of the issue in an earlier stage. Early interaction of stakeholders on both the substance and process will assist them to have passed the Forming and Stroming phase of the group prior to a VDC-session. A second improvement is related to the four core elements of a good process as defined by de Bruijn et al. (2010): *Openness, Protect of core values, Progress, and Substance*. By taking those elements into account while establishing process agreements (i.e. rules of the game), participants will be provided with enough prospect to let them serve their own interest during the decision-making process. The third and last opportunity for improving the road map is found in the optional activity of testing the process design prior to the start of the decision-making process. An activity which, although costly and time consuming, could be useful in cases where failure of the decision-making process is not an opinion. Meaning that utter indecision would lead to catastrophic outcomes like withdrawal of the project funds or even abolishment of the project. By merging the activities defined in the initial road map and the opportunities for improvements that were identified, a revisited version of the road map was developed, see figure 32.

The benefit of the improved road map is that it will allow stakeholders to interact with each other on both process and substance related issues prior to the decision-making process. This will cause them to develop a sense of ownership for the process and will make familiar with the group dynamics in an early stage. Which eventually will support the participating stakeholders to pass the phases of Forming and Storming prior to the decision-making process. In the end, this will be beneficial to the actual VDC-process, because it can focus completely on the task for which it was developed; improving the quality of the decision-making. Lastly, due to the fact that the revisited version of the road map is visualised in a decision-tree like manner, the practical implication of the road map has also improved significantly. Theoretically, VDC-experts could directly apply this road map when they are preparing for their next VDC-process. However, it must be mentioned that due to the fact the revisited version was not validated, an initial test case would be advised.

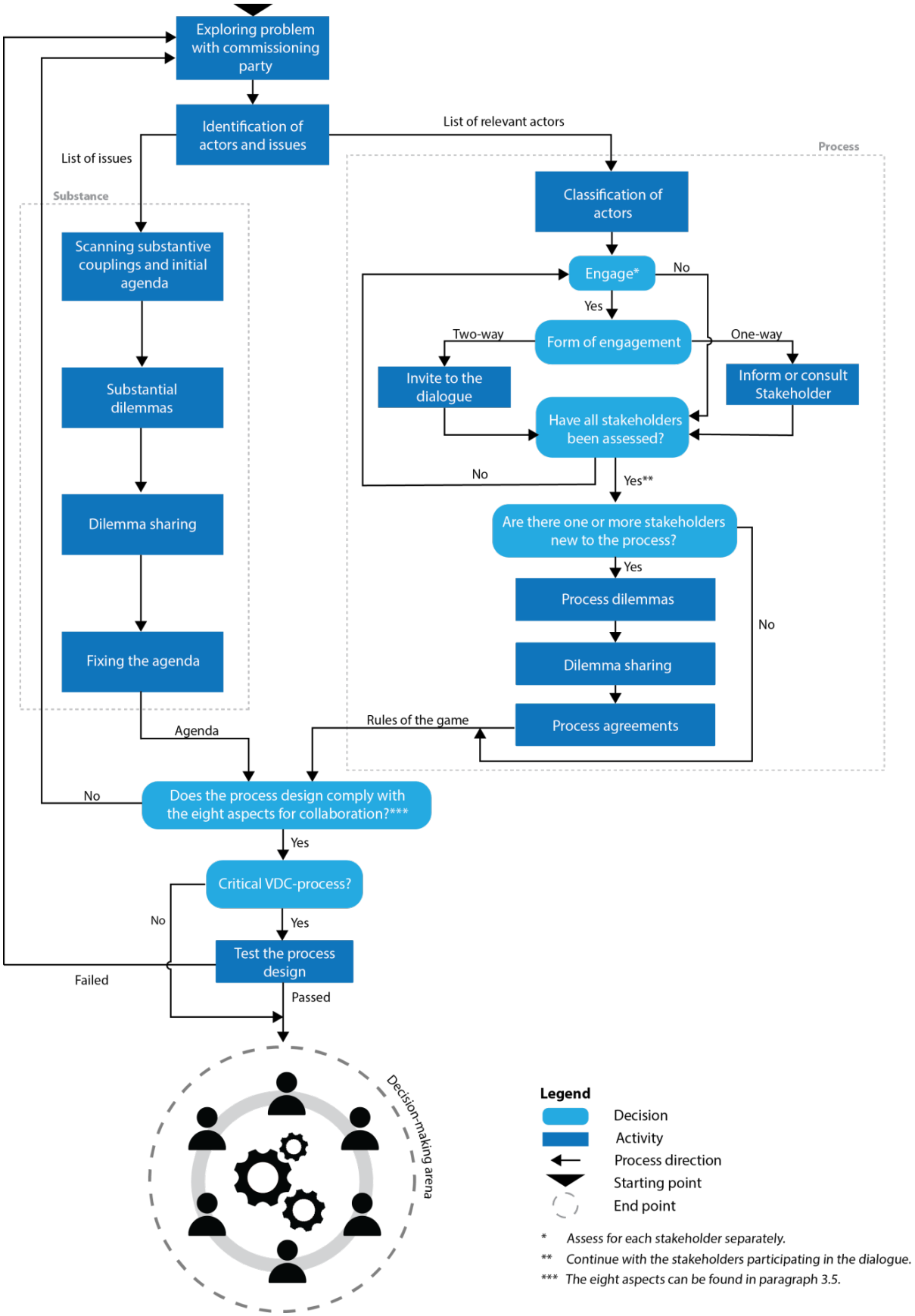


Figure 32: Revisited version of the road map.

With the knowledge gained in this research, people will be able to establish constructive collaboration among stakeholders in the run-up to a VDC-process. As a result, the decision-making quality will be improved because issues like misalignment of information during a discussion and unexpected behaviour of participants due to a mismatch in expectations can be prevented. Furthermore, this research has shown once again that a unilateral project approach will not be sufficient to solve complex issues in our contemporary society and that (constructive) collaboration among people is key to achieve a higher decision-making quality. Put differently, constructive collaboration can be seen as the key to reducing the amount of project failures in our world, because in the end it is people that need people to perform complex projects. As Henry Ford once said: *"Coming together is a beginning; keeping together is progress; working together is success".*

Therefore, the answer to the main research question is a road map with guidelines which assists VDC-experts of engineering organisations to develop constructive collaboration among stakeholders in the run-up to a VDC-process, so that the decision-making quality during a VDC-process will improve.

# 11 Recommendations and limitations

## 11.1 Recommendations for future research

In addition to the contribution the research made to the VDC body of knowledge, it has also highlighted several opportunities for future research. The following recommendations are given for future research.

- Throughout the whole research the general opinion was up hold that if a project team decides that a stakeholder is relevant to the project or project phase it must be invited to the run-up and actual decision-making process. However, what to do in case there are just too many relevant stakeholders who all need to be invited. In other words, no consensus was reached upon the question of what is the upper and lower bound to the number of stakeholders involved in order to still have a successful VDC-process in the end. Therefore, future research into the research area of *group size* and *group performance* would be suggested in order to further improve the road map.

- The first version of the road map was validated by means of a questionnaire conducted among VDC-experts however the revisited version of the road map was not validated. Therefore, it would be recommended to also perform a validation for the revisited version of the road map. If decided to perform a validation it is advised to include multiple organisations (i.e. not solely RHDHV) who have adopted VDC in order to test its validity. The Dutch engineering and construction firm BAM would for example be a valid candidate for an external validation because a conversation between the researcher and an employee of BAM suggested that, although not labelled as VDC, it uses a comparable method to improve decision-making in projects. In addition, BAM has acknowledged that they experience similar issues as observed in this research.

- The developed for the road map was triggered by the potential negative and positive influence of external stakeholders when invited to the decision-making process of a VDC-session. Due to this the road map is primarily aimed at preparing both internal and external stakeholders prior to a VDC-process together. However due to additional time and effort needed to structure the run-up to a VDC-process according to the roadmap, it would be interesting to investigate if the benefits of the road map still outweighs the costs in cases in which solely internal stakeholders are involved in the VDC-process. Or if the current approach, which is based on personal experience of VDC-experts, is more efficient in those cases.

## 11.2 Recommendations for RHDHV

Based on the conducted research, the following recommendations are given for Royal HaskoningDHV.

- During the many conversations of the researcher with employees of Royal HaskoningDHV, it appeared that many definitions of VDC existed. These definitions range from a technical perception in which BIM is seen as VDC, to an organisational perception in which VDC is only seen as a process accelerator. Therefore, it is recommended to Royal HaskoningDHV to redefine, with all cross-business line groups of VDC-experts, how they define VDC across the organisation. In doing so they can use the definition as presented in this research as support.

- Previous research by Stallen (2015), also conducted at Royal HaskoningDHV, has presented a strategy to improve implementation of VDC in an engineering organisation. In his research, Stallen identifies similar issues regarding the use of VDC within RHDHV. Although this research has been conducted more than a year ago no improvement was observed. Therefore, it would be recommended to the VDC-experts of Royal HaskoningDHV to critically assess the work of Stallen to see if it can help them to further implement VDC across their organisation and increase its business potential.

- The research has shown that the current application of VDC at Royal HaskoningDHV merely depends on personal experience of VDC-experts. Therefore, it would be recommended that besides adopting the road map as presented in this research, more tools must be developed to support employees with the application of VDC in projects. This will allow the VDC-approach to be more accessible to a wider range of engineers within the organisation and will assist the less-experienced and more technical-oriented engineers with the use of VDC.

- The results of the questionnaire indicated that although VDC-experts of RHDHV are of the opinion that preparation of a VDC-process is essential to the success of a session, they are not convinced about collaboration with others during the preparation. They prefer a unilateral run-up to an integral and dynamic process. In other words, they like to collaborate but only on their terms and conditions. This research however has shown that such an attitude is actually the cause of disturbance during a VDC-process because participants do not know what they can expect or what is asked of them. Therefore, RHDHV is advised to support their employees to overcome their fear for a multilateral process approach. Tools such as the road map as present in this research can be helpful in this because it will provide employees with guidance to explore the unknown. Furthermore, due to the fact that collaboration in decision-making is embedded in our Dutch society and that a unilateral approach to project often results in project failure a transition to an organisation which is accustomed with a multilateral, dynamic, and integral project approach will provide RHDHV with enormous business potential.

## 11.3 Research limitations

With regards to the data, research methodologies, and analysis used in this research the following limitations must be taken into consideration. The limitations affected the internal or external validity of this research. *Internal validity* is referred to as the quality and accuracy of the findings and *external validity* to the generalizability of the findings to another context.

### 11.3.1 Research data

With respect to the data used in this research, the following limitation must be taken into account.

- The data used for the case study and questionnaire were solely derived from RHDHV. The reason for that is that up till now, RHDHV is the first engineering organisation in the Netherlands that has adopted the VDC methodology of Stanford University. A consequence of this is that external validation of the research findings was difficult, affecting the generalizability of the research.

### 11.3.2 Research methodology

With respect to the applied methodology in this research, the following limitations must be taken into account.

- In the practical analysis of VDC, a case study of two engineering projects was performed. This provided in-depth knowledge of VDC in practice. However, due to the small number of projects studied in this research, generalizability of the results is difficult (i.e. reduces the external validity of the findings). (Verschuren & Hartog, 2005)
- The decision was made to conduct a questionnaire, because it provided the researcher with the opportunity to obtain a broad view of the subject and assess a large population. However, this approach also has some major limitations. The acquired knowledge by means of a questionnaire is of limited depth and the knowledge obtained is only related to a limited amount of variables of the research subject. (Verschuren & Hartog, 2005) This has reduced the internal validity of the research findings.
- The statements presented to the respondents in the questionnaire were formulated in a black and white perspective, leaving no room for nuances. The fact that the questions did not leave any room for nuance was experienced by two respondents as uncomfortable. This could indicate that the questions were possibly answered differently in case there was room for nuance. This suggests that the internal validity of the findings is less than expected.

### 11.3.3 Analysis

With respect to the used tools for data analysis, the following limitation must be taken into account.

- In general, when it is decided to perform statistical analysis on a dataset, parametric statics are always preferred over non-parametric statistics, because they are considered to be more powerful. However, due to the fact that the data derived from the questionnaire was on an ordinal scale, the researcher was limited to non-parametric statistics. The effect of this was that the chance of getting a non-rejected false Null-hypothesis (i.e. a Type-II statistical error) increased. (Carver & Nash, 2012; Vocht, 2009) This reduces the internal validity of the research.

# References


Achterkamp, M. C., & Vos, J. F. J. (2007). Critically identifying stakeholders: Evaluating boundary critique as a vehicle for stakeholder identification. . *Systems Research and Behavioral Science, 24*(1), 3-14.

Adler, P. S. (1995). Interdepartmental Interdependence and Coordination: The Case of the Design/Manufacturing Interface. *Organization Science, 6*(2), 147-167.

Baccarini, D. (1996). The concept of project complexity a review. *International Journal of Project Management, 14*(4), 5.

Baiden, B. K., Price, A. D. F., & Dainty, A. R. J. (2005). The extent of team integration within construction projects. *International Journal of Project Management, 24*(1), 13-23.

Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., Bakker, H., & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. *Elsevier*(29).

Bourne, L. (2005). *Project relationship management and the stakeholder circle.* (Doctor of Project Management), RMIT University, Melbourne.

Bourne, L., & Walker, D. H. (2008). Project relationship management and the Stakeholder Circle™. *International Journal of Managing Projects in Business, 1*(1), 125-130.

Bryson, J. M. (2004). What to do when stakeholders matter: stakeholder identification and analysis techniques. . *Public management review, 6*(1), 21-53.

C&S Engineering and Designing Group. (2016). BIM Modelling examples. Retrieved from http://www.candspmc.com/

Carver, R. H., & Nash, J. G. (2012). *Doing Data Anlysis with SPSS* Duxbury Press.

Chachere, J., Kunz, J., & Levitt, R. (2004). *Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration* Retrieved from California, US:

Chinyio, E., & Olomolaiye, P. (2009). *Construction Stakeholder Management*: John Wiley & Sons.

Cooke-Davies, T. (2002). The "real" success factors on projects. *International Journal of Project Management, 20*(3), 185-190. doi:http://dx.doi.org/10.1016/S0263-7863(01)00067-9

Cooper, R. G., & Kleinschmidt, E. J. (1990). *New products: The key factors in success.* . Chicago: American Marketing Association.

Crane, A., & Livesey, S. (2003). Are you talking to me? Stakeholder communication and the risks and rewards of dialogue. In J. Andriof, S. Waddock, S. Rahman, & B. Husted (Eds.), *Unfolding stakeholder thinking 2: relationships, communication, reporting and performance. Sheffield: Greenleaf: 39-52* (pp. 39-52). Sheffield: Greenleaf.

de Bruijn, H., ten Heuvelhof, E. F., & in 't Veld, R. (2010). *Process Management: Why Project Management Fails in Complex Decision Making Processes*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Deetz, S. (1995). *Transforming Communication, Transforming Business: Building Responsive and Responsible Workplaces*: Hampton Press.

Dijkstra, L. (2016) *Interview: Centrum Visie Zeist/Interviewer: X. v. Schie*. Amersfoort.

Eden, C., & Ackermann, F. (1998). *Making strategy: The journey of strategic management*. London: Sage Publications.

ENR. (2016). The 2015 Top 150 Global Design Firms 1-100. Retrieved from http://www.enr.com/toplists/2015_Top_150_Global_Design_Firms1

Eskerod, P., Huemann, M., & Ringhofer, C. (2015). Stakeholder inclusiveness: Enriching Project Management with General Stakeholder Theory. *Project management Journal, 46*(6), 42-53.

Eskerod, P., & Jepsen, A. L. (2009). Stakeholder analysis in projects: Challenges in using current guidelines in the real world. *International Journal of Project Management, 27* 335–343.

Eskerod, P., & L., J. A. (2013). *Project Stakeholder Management*. Farnham, Surrey: Gower Publishing.

Fischer, M. (2000). *CIFE's VDC Vision and Overview*. PPT Presentation. Center for integrated facility engineering. Stanford University of California. California, US.

Fitzpatrick, G., Kaplan, S., & Mansfield, T. (1996). *Physical spaces, virtual places and social worlds: A study of work in the virtual.* Paper presented at the Proceedings of the 1996 ACM conference on Computer supported cooperative work.

Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2003). *Megaprojects and Risk. An Anatomy of Ambition*. Cambridge: Cambridge University Press.

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*: Cambridge University Press.

Frooman, J. (1999). Stakeholder Influence Strategies. *The Academy of Management Review, 24*(2), 191-205.

Gantz, J., & Reinsel, D. (2012). *THE DIGITAL UNIVERSE IN 2020: Big Data, Bigger Digital Shadows, and Biggest Growth in the Far East*. Retrieved from Framingham:

Garcia, A. C. B., Kunz, J., Ekstrom, M., & Kiviniemi, A. (2003). *Building a Project Ontology with Extreme Collaboration and Virtual Design & Construction*. Retrieved from California, US:

Garland, R. (1991). The mid-point on a rating scale: Is it desirable. *Marketing bulletin, 2*(1), 66-70.

Gartner, I. G. (2015). Big Data. Retrieved from http://www.gartner.com/it-glossary/big-data/Gundecha

Gemeente Zeist. (2015). *Raadsvoorstel Centrumvisie*. Retrieved from Zeist:

Greenwood, M. (2007). Stakeholder Engagement: Beyond the Myth of Corporate Responsibility. *Journal of Business Ethics, 74*(4 %@ 1573-0697), 315-327. doi:10.1007/s10551-007-9509-y %U http://dx.doi.org/10.1007/s10551-007-9509-y

Hass, K. B. (2007). The Blending of Traditional and Agile Project Management. *PM world today, 9*(5), 8.

Haymaker, J., Ayaz, E., Fischer, M., Kam, C., Kunz, J., Ramsey, M., . . . Toledo, M. (2005). Managing communicating information on the stanford living laboratory feasibility study. *ITcon, 11*, 607-626.

Haymaker, J., Fischer, M., Kunz, J., & Suter, B. (2003). *Engineering Test Cases to Movitivate The formalization of an AEC Project Model as a Directed Acyclic Graph of Views and Dependencies*. Retrieved from California, US:

Haymaker, J., & Sutter, B. (2006). *Communicating, integrating, and improving multidisciplinary design and analysis narratives.* Retrieved from California, US:

Herriott, R. E., & Firestone, W. A. (1983). Multisite qualitative policy research: Optimizing description and generalizability. *Educational researcher*, 14-19.

Howard, R. A. (1988). Decision Analysis: Practice and Promise. *Management Science, 34*(6), 679-695.

Ihlen, Ø. (2013). Communicating with Stakeholders. In S. O. Idowu, N. Capaldi, L. Zu, & A. D. Gupta (Eds.), *Encyclopedia of Corporate Social Responsibility* (pp. 393-398). Berlin, Heidelberg: Springer Berlin Heidelberg.

Johannesson, P., & Perjons, E. (2014). *An Introduction to Design Science*: Springer International Publishing Switzerland.

Jung, Y., Jeong, M. G., & Mills, T. (2014). Identifying the Preferred Leadership Style for Managerial Position of Construction Management. *International Journal of Construction Engineering and Management, 3*(2), 47-56.

Kam, C. (2005). *Dynamic Decision Breakdown Structure: Ontology, Methodology, & Framework for Information Management in Support of Decision-Enabling Tasks in the Building Industry.* (PhD), Stanford University CA, US, California, US.

Kam, C., & Fischer, M. (2004). Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance—POP, PM4D, and decision dashboard approaches. *Automation in Construction, 13*(1), 53-65. doi:http://dx.doi.org/10.1016/j.autcon.2003.08.004

Khanzode, A., Fischer, M., Reed, D., & Ballard, G. (2006). *A Guide to Applying the Principles of Virtual Design & Construction (VDC) to the Lean Project Delivery Process*. Retrieved from California, US:

Kotter, J. P. (1996). *Leading change*: Harvard Business Press.

Kreifelts, T., Hinrichs, E., & Woetzel, G. (1993). *Sharing to-do lists with a distributed task manager.* Paper presented at the Proceedings of the Third European Conference on Computer-Supported Cooperative Work 13–17 September 1993, Milan, Italy ECSCW'93.

Kunz, J., & Fischer, M. (2012). *Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions*. Retrieved from California, US:

Kuutti, K. (1991). *The concept of activity as a basic unit of analysis for CSCW research.* Paper presented at the Proceedings of the Second European Conference on Computer-Supported Cooperative Work ECSCW'91.

Li, H., Lu, W., & Huang, T. (2009). Rethinking project management and exploring virtual design and construction as a potential solution. *Construction Management and Economics, 27*(4), 363-371.

Londoño, F., Cleetus, K. J., & Reddy, Y. V. (1991). A blackboard scheme for cooperative problem-solving by human experts. In D. Sriram, R. Logcher, & S. Fukuda (Eds.), *Computer-Aided Cooperative Product Development: MIT-JSME Workshop MIT, Cambridge, USA, November 20/21, 1989 Proceedings* (pp. 26-50). Berlin, Heidelberg: Springer Berlin Heidelberg.

Malone, T. W., & Crowston, K. (1990). *What is coordination theory and how can it help design cooperative work systems?* Paper presented at the Proceedings of the 1990 ACM conference on Computer-supported cooperative work.

Mark, G. (2002). Extreme Collaboration. *Communications of the ACM, 45*(6), 89-93.

Matell, M. S., & Jacoby, J. (1971). Is There an Optimal Number of Alternatives for Likert Scale Items? Study. *Educational and psychological measurement, 31*, 657-674.

McManus, B., & Cacioppe, R. (2011). An integral approach to project management. *Integral leadership*.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of management review, 22*(4), 853-886.

Morris, P. W. G. (1994). *The Management of Projects*. London, UK: Thomas Telford.

Morris, P. W. G. (2013). *Reconstructing Project Management.* Sussex, UK: John Wiley and Sons.

Mu, M., Mauthe, A., Tyson, G., & Cerqueira, E. (2012). *Statistical analysis of ordinal user opinion scores.* Paper presented at the Consumer Communications and Networking Conference (CCNC), 2012 IEEE.

Olander, S. (2003). *External Stakeholder Management in the Construction Process*. Retrieved from Lund, Sweden:

Oxford dictionaries. (Ed.) (2016) Oxford dictonary. Oxford, UK: Oxford University Press.

Patel, H., Pettitt, M., & Wilson, J. R. (2012). Factors of collaborative working: A framework for a collaboration model. *Applied Ergonomics, 43*(1), 1-26. doi:http://dx.doi.org/10.1016/j.apergo.2011.04.009

PMI. (2004). *A guide to the project management body of knowledge* (5th ed.). Newton Square, PA: Project management institute.

PMI. (2014). *A guide to the project management body of knowledge (PMBOK)* (4th ed.). Newton Square, PA: Project management institute.

PMI. (2015). *Capturing the Value of Project Management Through Decision Making*. Retrieved from

Preston, C. C., & Colman, A. M. (2000). Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica, 104*(1), 1-15. doi:http://dx.doi.org/10.1016/S0001-6918(99)00050-5

Rampaart, J. (2016) *Interview: Centrum Visie Zeist/Interviewer: X. v. Schie*. Amersfoort.

RHDHV. (2016). VDC Knowledge group site.

Ridder de, H. A. J. (2013). *Dynamic Control of Projects*. TU Delft. Delft.

Roselaar, S. (2016) *Interview: Alternatieve studie spoorwegovergangen Ermelo/Interviewer: X. v. Schie*. Amersfoort.

Royal Haskoning DHV. (2012). *Ermelo; alternatieven studie - project plan*. Royal Haskoning DHV. Amersfoort.

Royal Haskoning DHV. (2015a). *Annual report 2015*. Retrieved from Amersfoort:

Royal Haskoning DHV. (2015b). *Uitvoering ontwerp- bestek- en aanbestedingsfase herinrichting centrumvisie*. Royal Haskoning DHV. Amersfoort.

Royal Haskoning DHV. (2015c). Virtual Design & Construction *Sneller, beter, slimmer* (pp. 6). Amersfoort: Royal Haskoning DHV.

Royal Haskoning DHV. (2016). Royal HaskoningDHV's Half Year Figures 2015. Retrieved from https://insight.rhkonnections.com/news.html?view=entry&layout=show&id=2221

Shepherd, A., & Bowler, C. (1997). Beyond the Requirements: Improving Public Participation in EIA. *Journal of Environmental Planning and Management, 40*(6), 725-738.

Smith, D., & Edgar, E. (2008). Building Information Modeling (BIM). Retrieved from http://www.wbdg.org/bim/bim.php

Soliman, R., Braun, R., & Simoff, S. (2005). *The essential ingredients of collaboration*.

Špundak, M. (2014). Mixed Agile/Traditional Project Management Methodology – Reality or Illusion? *Procedia - Social and Behavioral Sciences, 119*, 939-948. doi:http://dx.doi.org/10.1016/j.sbspro.2014.03.105

Stallen, N. (2015). *The Use and Adoption of Virtual Design and Construction in Engineering Organizations.* (Master Degree), Delft University of Technology, Delft.

Suchman, M. C. (1995). Managing Legitimacy: Strategic and Institutional Approaches. *The Academy of Management Review, 20*(3), 571-610. doi:10.2307/258788

Teege, G. (1996). Object-oriented activity support: a model for integrated CSCW systems. *Computer Supported Cooperative Work (CSCW), 5*(1), 93-124.

Thomas, J. C. (1995). *Public participation in public decisions: New skills and strategies for public managers*: Jossey-Bass.

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological bulletin, 63*(6), 384.

Turkulainen, V., Aaltonen, K., & Lohikoski, P. (2015). Managing Project Stakeholder Communication: The Qstock Festival Case. *Project management Journal, 46*(6), 74-91. doi:10.1002/pmj.21547

Ulrich, W. (1983). *Critical heuristics of social planning: A new approach to practical philosophy*. Chichester: Wiley.

Van Twist, M., Edelenbos, J., & van der Broek, M. (1998). In dilemma's durven denken. *Management en Organisatie, 52*(5), 7-23.

Verschuren, P. J. M., & Hartog, R. J. M. (2005). Evaluation in Design-Oriented Research. *International Journal of Methodology*(39), 733 - 762.

Vocht, A. d. (2009). *Basishandboek Statistiek met SPPS Statistics 17*. Utrecht: Bijveld Press.

Williams, T. M. (2002). *Modelling Complex Projects*. London: John Wiley & Sons.

Winch, G., & Bonke, S. (2002). Project Stakeholder Mapping: Analysing the Interests of Project Stakeholders. *Project Management Institute (PMI), Chapter 23 in The Frontiers of Project Management Research*, 385-403.

Yin, R. K. (2009). *Case study research: design and methods* (Fourth edition ed. Vol. 5): SAGE publications Inc.

Zeist, C. V. (2016). Centrum Zeist Vernieuwt. Retrieved from https://www.centrumzeistvernieuwt.nl/project/fasering/

Zutt, R. (2016) *Interview: Alternatieve studie spoorwegovergangen Ermelo/Interviewer: X. v. Schie*. Rotterdam.

# Appendices

## Appendix A: Information management in VDC

In this section the information management and decision-making process of the VDC methodology will be assessed. This is done by studying the literature on how it has reacted to the absence of formal methods and processes to structure the information management and decision-making process. In order to guide this process, the following research question was formulated.

> *How is the Virtual Design and Construction information management and decision-making process described in the literature?*

### Structuring the information management and decision-making process

Several researcher of Stanford University's CIFE have addressed the lack of formal methodologies to structure the information management and decision-making process among multiple parties and disciplines. (Haymaker et al., 2005) The outcome of these studies is the development of three formal methodologies that focus on managing information more quickly and accurately, and the enhancement of communication processes within a multi-party, multi-disciplinary design process. The first methodology, which is the POP methodology, is focussed on enabling professionals to create a descriptive and balanced overview of the project information. The second methodology, Narratives, and the third methodology, Decision Dashboard, are both methods that are aimed at helping AEC professionals to manage, communicate different kinds of information among stakeholders, and track decision-making in a project. (Haymaker et al., 2005)

#### POP methodology

The POP methodology is also discussed generically in chapter 2. However, the methodology can also be used to manage project information in a VDC process.

Applying the POP methodology in the context of information management makes it possible for AEC professionals to organise project information models in terms of function, forms, and behaviours of the project product, organisation and processes. (Haymaker et al., 2005) It is a static representation of information shared among disciplines and models with the objective to assure consistency between function, form and behaviour of each of the P, O, and P models.

This representation of project information can be made on different hierarchical levels of detail and is often based on the project's breakdown structure and level of detail, e.g. Organisational Breakdown Structure, Work Breakdown Structure, and Project Breakdown Structure. At the highest level, Level-A, each item in a POP model represents a single element e.g. building, design and construction team, design and construction process. On Level-B, each item represents 10% of the cost, efforts, or scheduled duration of a project and Level-C represents items that represent 1% of the cost, efforts, or schedule duration of a project. These levels continue till the required level of detail of a project is met. In other words, the level of detail in a POP-model is project and project phase dependent.

In the table 14, an example of Haymaker et al. (2005) for a POP-model for the purpose of managing and communicating information is given. The example is focussed on classifying information needed to decide on the room type for the Living Laboratory at Stanford University. The Living Laboratory was a housing project of the Stanford University in 2005. The building needed to house fifty students and serve as a test bed for research and education on sustainable building and living.

In the function column of the product row a list with objectives is displayed which should be fulfilled by the building design. These objectives are in the next column translated into possible design choices, varying from building lay-out and number of beds to bathroom facilities. In the last column, behaviour, categories with respect to the objectives and design possibilities are listed to determine and measure the performance of the design.

In the organisation category, the column 'Function' specifies information required in the organisation to represent the different interests of stakeholders. From this can be concluded that a multidisciplinary organisation is required to achieve a good design. The column 'Form/Scope' describes the composition of this organisation. This list of actors and stakeholders represents the group of people that is required to achieve a good design. Lastly, in the column 'Behaviour', measurements to determine how well this multi-disciplinary organisation is contributing to the design process are given.

In the row 'Process' a description in the context of function, form, and behaviour is given. This should be followed by the organisation to achieve the design objectives. In the column 'Function', objectives such as the involvement of students in the decision-making process is found. In the subsequent column, processes in which the previously defined objectives should be incorporated are mentioned. Lastly, in the column 'Behaviour' items are defined to measure the process performance in terms of risks, cost, and time.

| | **Function:** Objectives | **Form/Scope**: Design choices | **Behaviour**: Predictions |
|---|---|---|---|
| **Product** | | | |
| | • Enable privacy<br>• Popular with students<br>• Encourage social interaction<br>• Suitable for summer use<br>• Efficient with space<br>• Efficient with plumbing<br>• Efficient with structure<br>• Flexible for future reconfiguration<br>• Efficient with energy | • Singles<br>• Doubles<br>• Triples<br>• Quads<br>• Sinks<br>• Showers<br>• T Shape lay-out<br>• U Shape Lay-out<br>• H-shape lay-our | • Privacy<br>• Popularity with students<br>• Social interaction<br>• Suitability for summer use<br>• Material Efficiency<br>• Plumbing efficiency<br>• Energy efficiency<br>• Space efficiency<br>• Flexibility |
| **Organisation** | | | |
| | • Environmental knowledge<br>• Dorm residence knowledge<br>• Economic knowledge<br>• Include student input | • Architects<br>• Project manager<br>• University architect<br>• Student representatives<br>• Energy consultant<br>• Structural Consultant<br>• Housing | • Environmental knowledge<br>• Dorm residence knowledge<br>• Student input |
| **Process** | | | |
| | • Involve Student input<br>• Reasonable cost<br>• Reasonable time<br>• Be rigorous | • Lay out on site<br>• Assess material efficiency<br>• Assess privacy<br>• Assess social interaction<br>• Assess energy efficiency<br>• Assess flexibility<br>• Assess summer usability<br>• Decide on room type<br>• Decide on restroom type | • Student input<br>• Cost<br>• Reasonable time<br>• rigor |

Table 15: POP model for the project information the room type decision (Haymaker et al., 2005, p. 7)

### Narrative methodology

The Narrative[12] Methodology is developed by J. Haymaker, M. Fischer, J. Kunz, and B. Sutter and is based on the notion that nowadays the AEC industry, due to its unique, multi-disciplinary, constructive, and iterative nature, lacks simple, flexible, and formal frameworks for communicating and integrating information processes amongst different disciplines. This causes the industry to struggle with accurate and quickly created balanced and near-optimal multi-disciplinary designs. (Haymaker et al., 2005; Haymaker et al., 2003; Haymaker & Sutter, 2006) In other words, due to the transition in project approach, there is no suitable information management method or framework available to guide the process of sharing and managing information in projects.

Haymaker et al. (2005, p. 2) describe the application of the Narrative Methodology as follows: *"AEC professionals can use Narratives to graphically and formally define required functions, propose forms, analyse the behaviours of these forms, and manage and communicate the dependencies among these distributed, interdependent, evolving models"*. The Narrative methodology can be seen as a framework which enables project team members to construct, manage and control project information with its dependencies in a formal and visual manner. The narrative framework can be decomposed into three groups of methods; representation, reasoning, and management.

[12] '*Narrative*' a spoken or written account of connected events; a story. (Oxford dictionaries, 2016)

1. **Representation**: Besides its focus on representing task-specific information, these methods are also focussed on representing the dependencies between the information. Haymaker and Sutter (2006) propose that the source of information, status of integration of information in relation to the source, and the nature of reasoning that construct the information from its information sources must be represented.
2. **Reasoning:** These methods are aimed at defining the nature of information dependencies, both in a manual and automated manner.
3. **Management:** Management methods can be used by project personnel to manage the integration of information and information processes. It will support them to iteratively construct the information and be notified when information sources on which other information is based has been changed.

In figure 29, a step-by-step explanation is given about Haymaker and Sutter (2006)'s Narrative Methodology. In the upper left-hand corner, A, the source of information, nature of information, and status of the dependency between the different sources of information is described. By repeating this process, a narrative is developed by using narrative questions such as; '*Who did what?', 'What information is Produced?',* and '*What does it look like?'.* Eventually, this results in a visualised, computer-based narrative, see D, integrating communication and sources of information. One can conclude that this methodology treats the same elements of Product, Organisation, Process, Function, Form, and Behaviour as the POP methodology does.

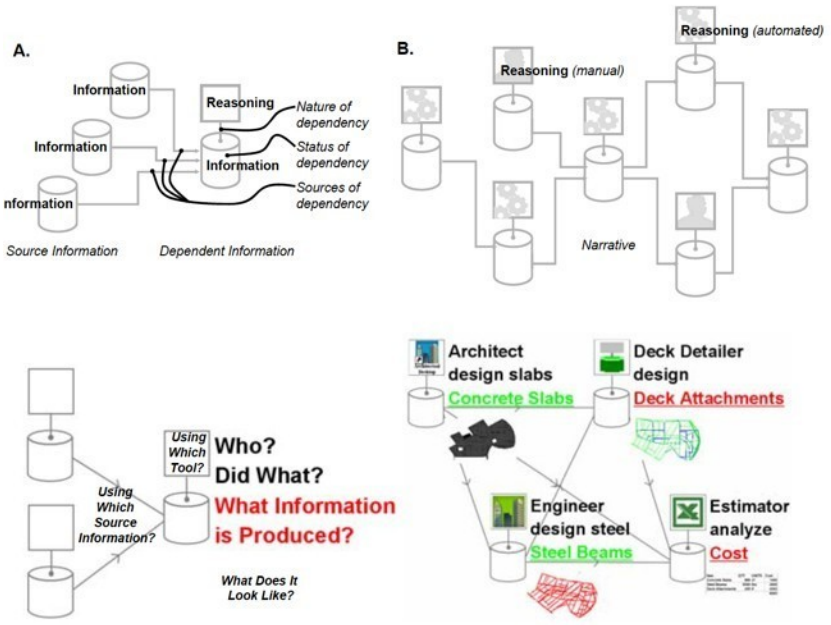


Figure 33: Step by step explanation of the Narrative methodology. (Haymaker & Sutter, 2006, p. 11)

### Decision Dashboard methodology

The Decision Dashboard methodology is developed by Calvin Kam and is aimed at allowing project teams to interactively change, evaluate and document design decisions. Communication and sharing these design decisions with other stakeholders is being enabled. (Haymaker et al., 2005)

Kam (2005) uses the theories of Decision Analysis, Virtual Design and Construction, and the AEC industry as the theoretical points of departure for his dissertation in which the Decision Dashboard is presented. Although in all theories discussed decision-making objectives occur, they do not provide a proper representation, methodology and process for AEC decision information management to create a good and consequent decision-making process. Due to this, AEC professionals have difficulties with reusing information and performing analysis when other design alternatives appear in a design process. With the current method, extra design alternatives will result in rework and inevitable process delays. (Kam, 2005) In other words, due to the fact that there is no proper representation, methodology and process for AEC decision information management, the number of design alternatives which can be explored during the design process, without performing rework and experiencing delays, is limited.

The decision Dashboard methodology addresses the three limitations of representation, methodology and process in the following way.

1. **Representation**
   By formulizing an ontology for decision stakeholders and computer programs, vocabulary was created to represent and structure decision information. This representation method of decision information is called a Decision Breakdown Structure (DBS). The ontology of the DBS consists out of three main features; elements, relationships, and attributes.

| Ontology | |
|---|---|
| **Elements** | • Decision topics<br>• Decision criteria<br>• Decision options<br>• Decision alternatives |
| **Relationships** | • Aggregate relationships<br>• Choice relationship<br>• Requirement relationship<br>• Impact relationship<br>• Process relationship |
| **Attributes** | • Level 1 – embedded decision information (e.g. values, text, etc.)<br>• Level 2 – external electronic information (e.g. computer applications or databases) |

Table 16: Decision Dashboard ontology. (Kam, 2005)

2. **Methodology**
   On the basis of the Decision Dashboard ontology, Kam (2005) created a Decision Method Model to manage the information in the decision-making process in a dynamic manner. The Decision Method Model consists out of six base methods and four composite methods. The table below represents an enumerated overview of the base and composite methods.

| Methods | |
|---|---|
| **Base methods** | B1: Manage Decision Ontology<br>B2: Couple, de-couple, and re-couple ontology elements<br>B3: Distinguish ontology elements between selected and candidate states<br>B4: Reference existing decision information<br>B5: Filter graphical representation of AEC decision ontology<br>B6: Evaluate in different contexts and across different levels of detail |
| **Composite methods** | C1: Formulate a Decision breakdown<br>C2: Swap ontology elements between selected and candidate states<br>C3: Interact in the CIFE I-Room<br>C4: Filter graphical representation of a Decision Breakdown Structure |

Table 17: Decision Method Model. (Kam, 2005) (Kam, 2005) (Kam, 2005) (Kam, 2005)

3. **Process**

The process of Kim formulates five information management phases instead of the black and white two phase reasoning of 'definition' and 'decision'. The application of the five phase information management process is presented in the form of a framework called Dynamic Decision Breakdown Structure Framework. This framework combines the Decision ontology, Decision Method Model, and the five decision phases.

| Framework phases | Applicable Ontology and Decision Method Model |
|---|---|
| **Decision / Definition** | Outline the Decision Breakdown Structure (DBS) with the following ontology parts:<br>Elements: decision topics, criteria Relationships: aggregate, requirement<br><br>C1: Formulate a Decision Breakdown Structure<br>C4: Filter Graphical Representation of a Decision Breakdown Structure |
| **Formulation** | All ontology elements and relationships that are needed to develop a complete DBS<br><br>B6: Evaluate in Different Contexts and Across Different Levels of Detail<br>C1: Formulate a Decision Breakdown Structure<br>C2: Swap Decision Information Between Selected and Candidate States<br>C4: Filter Graphical Representation of a Decision Breakdown Structure |
| **Evaluation** | All ontology elements and relationships from the DBS<br><br>B1: Manage Decision Information, Relationships, and Attributes<br>B6: Evaluate in Different Contexts and Across Different Levels of Detail<br>C3: Interact in the I-Room Environment<br>C4: Filter Graphical Representation of a Decision Breakdown Structure |
| **Iteration** | All ontology elements and relationships that are needed to modify the existing DBS<br><br>B1: Manage Decision Information, Relationships, and Attributes<br>B6: Evaluate in Different Contexts and Across Different Levels of Detail<br>C1: Formulate a Decision Breakdown Structure<br>C2: Swap Decision Information Between Selected and Candidate States<br>C3: Interact in the I-Room Environment<br>C4: Filter Graphical Representation of a Decision Breakdown Structure |

| | |
|---|---|
| **Decision** | Document and archive the DBS with the ontology attributes present in the elements and relationships<br><br>B1: Manage Decision Information, Relationships, and Attributes<br>B4: Reference Existing Decision Information |

Table 18: Application framework of the Decision Ontology and Decision Method Model.(Kam, 2005)

Similar to the example of the POP, the example in figure 30 represents a Decision Dashboard for the open doubles room-type decision relating the Living Laboratory at the University of Stanford. The grey squares represent decision topics, yellow and blue triangles represent alternative, and the blue and yellow circles options. The difference between yellow and blue option is that the yellow figure is the selected one in the current alternative and the blue option is a possible option or i.e. alternative.

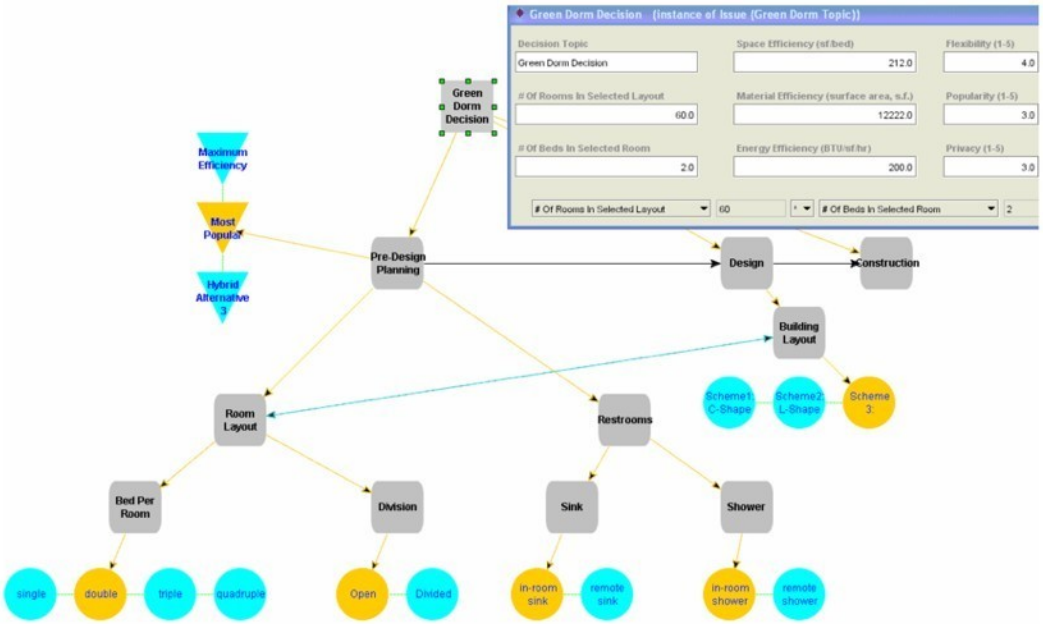


Figure 34: Decision Dashboard example for open doubles room type.(Haymaker et al., 2005, p. 10)

### Comparing the methodologies

As Haymaker et al. (2005) already stated, the main difference between the three methods is that the POP methodology is focussed on creating a descriptive representation model of project information and the Narrative and Decision Dashboard methodology is focussed on managing and communicating specific kinds of relationships between these information models. Therefore, the POP methodology can be associated with a level one VDC-maturity and the Narrative and Decision Dashboard with a level two maturity. In table 18, a more in-depth comparison is made between the different methodology on the basis of their features, operability, and applicability.

| | Methodology | | |
|---|---|---|---|
| **Features** | POP | Narrative | Decision Dashboard |
| 1 Integration of Product, Organisation, and Process | Yes | No | Yes |
| 2 Link between POP and form, function, and behaviour | Yes | Partly | Yes |
| 3 Link between information source and reasoning | No | Yes | Yes |
| 4 Multiple decision aspects | No | Yes | Yes |
| 5 Traceability of decision-making | No | Yes | Yes |
| 6 Multiple decision angles (stakeholders) | Yes | Yes | No |
| 7 Visualisation of information interdependencies | No | Yes | Yes |
| **Operability** | | | |
| 1 Dynamic or static model | Static | Static | Dynamic |
| 2 Computer-based | No (Yes)[13] | Yes | Yes |
| 3 IT-skills required | No | Yes | Yes |
| **Applicability** | | | |
| 1 Developed for or in context of VDC | Yes | No | Yes |
| 2 Applicable at all levels of detail | Yes | Yes | Yes |

Table 19: Comparison of information management methodologies.

Besides the above comparison, it can be noticed that all three methodologies are focussed on the structuring the information management and decision-making process when all information and stakeholders are known in a project. In other words, the POP, Narrative, and Decision-Dashboard are only aimed at the processing and output part of the process and not at the input. This in visualised in the picture below.


Figure 35: Simplified representation of the information management and decision-making process.

## Conclusion

After conducting a literature study on how the literature has dealt with the lack of formal processes and methods to structure the information management and decision-making process in the context of VDC; the POP, Narrative, and Decision Dashboard methodologies were found. In short, the POP methodology is a static representation of information shared among disciplines and models with the objective to assure consistency between function, form and behaviour of each of the Product,

[13] Computer-based if matrix is constructed by the aid of software.

Organisation, and Process models. The narrative is a methodology that constructs, manages and controls project information with its dependencies in a formal and visual manner and the Decision Dashboard methodology allows project teams to interactively change, evaluate and document design decisions and makes it possible to communicate and share these design decisions with other stakeholders.

After making a comparison between the difference methodologies it was concluded that despite their own way of representing and managing information all methods were essentially aimed at structuring the information management and decision-making process. The question of which information and who is needed during the information management and decision-making process was not answered. In other words, the methodologies are based on an ideal situation in which all stakeholders and information is known and readily available in the process.

# Appendix B: case study

*It must be mentioned that the analyses found in this section were conducted out of the perspective of an information process. The reason for this is that at the beginning of this research the aim was on the information management process of VDC. However, the results of this analysis learned the researcher that the actual potential for an improvement to the VDC-process was not in the information management process but in structuring the run-up to a VDC-process. Nonetheless the results are still applicable to the current scope of this research.*

## Case selection

In the table below an overview can be found of the case study selection process. It must be noticed that all cases are infrastructure projects executed by RHDHV and that in order to be a unit of analysis the case must meet all criteria.

| | Noordelijke randweg Teylingen | Kunstwerken ring Utrecht | Centrum Visie Zeist | Nijmegen | Railway crossing Ermelo | Veenendaal |
|---|---|---|---|---|---|---|
| **Project status** | Completed | Ongoing | Ongoing | Ongoing | Completed | Ongoing |
| **Full spectrum of P, O, and P** | Yes | Yes | Yes | Partially | Yes | No |
| **Tendered as VDC project** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Executed as VDC project** | Partially | No | Yes | Yes | Yes | Yes |
| **Access to project documentation** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Access to project personal** | No | Yes | Yes | Yes | Yes | Yes |
| | | | **Selected** | | **Selected** | |

*Remainder of the appendix B has been deleted due to confidentiality reasons*

# Appendix C: Research methodology

## Questionnaire

Below the questionnaire as distributed among the VDC-experts can be found.

*Welkom, fijn dat u even de tijd neemt om deze korte vragenlijst in te vullen.*

*Het doel van deze vragenlijst is om inzicht te krijgen in de voorbereiding van een Virtual Design and Construction sessie en de samenwerking in deze voorbereiding. In deze vragenlijst zullen er verschillende stellingen aan u worden gepresenteerd waarover uw mening wordt gevraagd. Er bestaan dus geen goede of foute antwoorden.*

*De resultaten van de vragenlijst worden volledig anoniem in het onderzoek gebruikt maar ten behoeve van eventuele suggesties van uw zijde zal in de eerste vraag naar uw naam worden gevraagd.*

*Alvast bedankt voor uw tijd!*

*Xander van Schie*

### 1. Algemeen

**Q1: Wat is uw naam?**
**…..**
*(De resultaten worden geanonimiseerd voor het gebruik in het afstudeeronderzoek).*

**Q2: Onder welke business-line valt u?**
1: Buildings/ 2: Transport & Planning/ 3: Anders…

In hoeverre bent u het eens met de volgende stelling:
**Q3: Transport & Planning-projecten worden gekenmerkt door meer stakeholders dan Building-projecten.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q4: In hoeveel projecten heeft u gewerkt met Virtual Design and Construction?**

| *1: Geen* | *2: 1 tot 5* | *3: 6 tot 10* | *4: 11 of meer* |
|---|---|---|---|
| ○ | ○ | ○ | ○ |

**Q5: Hoe ervaren acht u zich met betrekking tot Virtual Design and Construction?**

| *1: Beginner* | *2: Gevorderde* | *3: Expert* |
|---|---|---|
| ○ | ○ | ○ |

**Q6: Hoe groot is in uw ogen de toegevoegde waarde van Virtual Design en Construction in een project?**

| *1: Geen* | *2: Zeer klein* | *3: Klein* | *4: Groot* | *5: Zeer groot* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

## 2. Stellingen – Voorbereiding

*In het komende gedeelte worden er twaalf stellingen gegeven. Vier over de voorbereiding van een Virtual Design and Construction sessie en acht over de samenwerking in deze voorbereiding. Aan u wordt gevraagd in hoeverre u het eens bent met de stellingen.*

*U kunt de stellingen beoordelen op een schaal van: helemaal oneens/oneens/neutraal/eens/helemaal eens.*

**Q7: De voorbereiding is essentieel voor het slagen van een Virtual Design and Construction sessie.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q8: Aan de voorbereiding van een Virtual Design and Construction-sessie moeten alle interne stakeholders* meewerken.**

** Interne stakeholders (i.e. projectteam) bestaat uit alle betrokken disciplines van RHDHV, de klant en andere actief betrokken partijen.*

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q9: Interne stakeholders* moeten getraind zijn in Virtual Design and Construction methode.**

** Interne stakeholders (i.e. projectteam) bestaat uit alle betrokken disciplines van RHDHV, de klant en andere actief betrokken partijen.*

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q10: Externe stakeholders** moeten_worden belast met de Virtual Design and Construction methode tijdens de voorbereiding.**

***Partijen die passief betrokken zijn bij het project zoals belangenorganisaties.*

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

## 3. Stellingen – samenwerking in de voorbereiding

**Q11: De voorbereiding van een Virtual Design and Construction sessie moet in samenwerking met twee of meer stakeholders gebeuren.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q12: Er moet een gedeeld medium beschikbaar zijn in de voorbereiding van een Virtual Design and Construction-sessie waarop stakeholders kunnen communiceren en informatie kunnen uitwisselen.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q13: Bij een gebrek aan tijd is samenwerking tussen stakeholders in de voorbereiding te verwaarlozen.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q14: Er moet een gezamenlijk doel zijn onder stakeholders anders is samenwerken niet mogelijk.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q15: De focus moet liggen op het gezamenlijke doel anders zal de samenwerking tussen stakeholders falen.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q16: Voor samenwerking moet er een gemeenschappelijke taal* beschikbaar zijn die communicatie tussen de stakeholders mogelijk maakt.**

* Bijv. Taal (Nederlands/Engels)/Jargon/pictogrammen/etc.

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q17: Een stakeholder moet kennis hebben van het probleemgebied anders is deelname aan de voorbereiding voor deze partij nutteloos.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Q18: Interactie tussen stakeholders in de voorbereiding moet worden gestimuleerd en gemonitord.**

| *1: Helemaal oneens* | *2: Oneens* | *3: Neutraal* | *4: Eens* | *5: Helemaal eens* |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

## 4. Feedback

**Q19: Als u naar aanleiding van de genoemde stellingen nog essentiële aspecten met betrekking op samenwerking en/of voorbereiding mist, kunt u hieronder een opmerking plaatsen.**

….

## Pilot sessions

Before the questionnaire was distributed among the research population four pilot test sessions were held. On the basis of these sessions the following adjustments were made to the questionnaire.

The first pilot session was held with L. Dijkstra a VDC operator of RHDHV. (L. Dijkstra, personal communication, May 17, 2016)

- In question three *infrastructure projects* was replaced by *Transport & Planning projects* in order to maintain consistency in the questionnaire.
- Suggestion was made to add numerical values to the Likert-scale to provide the in respondents with a reference scale.
- Likert-scale for question six was adjusted to *Geen/Zeer Klein/Klein/Groot/Zeer groot.*
- In order to prevent interpretation differences the word *participants* was replaced by *stakeholders* in question elven.

The second pilot session was held with one on the graduation committee members and on the basis of this the following adjustments were made. (S. van Nederveen, personal communication, May 18, 2016)

- The size of the cartoon was adjusted to make it readable on first sight. This with as objective to increase the initial response.
- The suggestion of L. Dijkstra for adding numerical values to the Likert-scale was confirmed and therefore integrated into the questionnaire.

Third session was held with an independent scientist (i.e. not involved in this research) of the Delft University of Technology. (R. Schoenmaker, personal communication, May 18, 2016)

- A third category '*other*' was added to question two. This to keep the possibility open that a respondent is not working in the suggested business lines anymore.
- The written introduction to the statements was adjusted to make it clearer in what context the statements must be judged.

The last pilot session was held with an unknowing and independent person and on the basis of this session the following adjustments were made. (D. van Schie, personal communication, May 18, 2016)

- Some small grammatical and spelling errors were corrected.
- The introduction to the questionnaire was adjusted because the initial version suggested the search for a correlation between collaboration and collaboration while preparing. In other words, the search for a correlation with a correlation and this is not the case in this questionnaire.

## Data codification

Below the data codification table can be found.

| Question | Alphanumerical values | Numeric value |
|---|---|---|
| **Q2** | *Buildings* | 1 |
| | *Transport & Planning* | 2 |
| | *Other* | 3 |
| **Q4** | *Geen* | 1 |
| | *1 tot en met 5* | 2 |
| | *6 tot en met 10* | 3 |
| | *11 en meer* | 4 |
| **Q5** | *Beginner* | 1 |
| | *Gevorderde* | 2 |
| | *Expert* | 3 |
| **Q6** | *Geen* | 1 |
| | *Zeer klein* | 2 |
| | *Klein* | 3 |
| | *Groot* | 4 |
| | *Zeer groot* | 5 |
| **Q3 and Q7-Q 19** | *Helemaal oneens* | 1 |
| | *Oneens* | 2 |
| | *Neutraal* | 3 |
| | *Eens* | 4 |
| | *Helemaal eens* | 5 |