Building Information Modeling
Towards a structured implementation process in an engineering organization

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Disclaimer This is the final thesis report for the master study Construction Management and Engineering at the Delft University of Technology. The research was performed by R.M. Panaitescu on a case study within Grontmij Nederland. The investigation aims to investigate the challenges of BIM implementation within an engineering organization and to develop an implementation plan framework fit for the case of the commissioning organization. The later should be aware of its limitations and develop and adjust the framework accordingly to their own purpose.

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Abstract

The traditional process for delivering facilities in the AEC industry is fragmented and uses two-dimensional drawings modes of communication. These aspects are considered to be accountable for large inefficiencies within the industry along with the inconsistent adoption of technology. The errors and omissions attributed to this practices lead to increasing of costs, delays and lawsuits between project parties.

As a solution to inefficiencies in the industry, and inspired from other industries, BIM technology has been gradually developed and started to be practically used in the AEC industry in projects starting from the mid-2000s.

A commonly accepted definition of BIM is: “Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.” (U.S. National BIM Standard – NBIMS)

With BIM technology, a virtual model of a building’s characteristics is created. The main features of the building model are: the components are represented with objects with intelligent manipulation due to parametric rules, the components include data that describes how they behave and data is consistent and non-redundant.

For an engineering organization, the main benefits that BIM usage provides are:

- centralized, consistent and non redundant lifecycle project information
- automatization of project analysis through software tools for: clash detection, cost estimation, time planning, energy use, allowing for project efficiency gains, decrease of inconsistencies and mitigation of project risks

Nevertheless, the adoption of BIM should not be treated as an ad hoc activity. The novelty and the complexity of the changes are hampering the process bring many challenges. Therefore, successfully implementing BIM does not resume to upgrading the software and training. But rather it requires changes in almost all aspects of the organization. Furthermore, understanding of the technology and related processes and an implementation plan prior to the conversion.

This research is passed on a two phase plan, first intending to analyze the main challenges for BIM adoption within and engineering organization and second focusing on developing a set of recommendations addressing these challenges towards creating an effective implementation plan template relevant for the commissioning organization. The commissioning organization is the engineering company Grontmij, the research being supported by the Wegen Department within this company.

The main BIM implementation challenges have been derived through literature review and structured through a technology adoption theory framework. Further, the case study at Grontmij has validated the findings, with a few omissions based on the specificity of projects carried out by the organization.
The main challenges for adopting BIM within an engineering organization are:

- Environmental context challenges: insufficient level of clients’ awareness and requesting of BIM services on projects and level of BIM adoption at industry level.
- Organizational challenges: the extent of the implementation costs correlated with a lack of fast increase in project efficiency for the organization; difficult development of an organizational common policy and set of goals for the new technology; changes required for integration within the business model; the development of BIM modeling skills and associated redefining of staff roles.
- Individual adoption challenges: overcoming individual comfort with familiar working methods and required individual drive towards change.
- Innovation specific challenges: interoperability difficulties between project disciplines; scalability of BIM models and compatibility with current systems.

From this perspective, the research considers addressing each relevant challenge as a requirement for creating the BIM implementation plan framework that aims to structure the adoption of BIM within an engineering organization.

The main actions composing the framework are presented in Table 1 related to the responsible decision making level.

**Table 1 Actions of BIM Implementation Plan Framework**

<table>
<thead>
<tr>
<th>BIM Initiative Group Actions</th>
<th>Strategic Level Actions</th>
<th>Tactical Level Actions</th>
<th>Operational Level actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Internal Marketing - Company Level</td>
<td>2. Establish Strategic BIM Support Group and allocate resource support</td>
<td>2. Develop business model for BIM</td>
<td>2. Technical resource development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Technical resource plan</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Internal Marketing - Department Level</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. Collaboration and Procedural Protocol</td>
<td></td>
</tr>
</tbody>
</table>

The structured approach proposed in this report, frameworks all BIM implementation actions based on the implementation phasing from technology implementation theory and the responsibility attribution based on levels of decision making within an organization. Thus the research converges towards creating a BIM implementation plan framework for an engineering organization, relevant for the case of the commissioning organization.
Foreword

The concluding phase of my master studies, writing the graduation thesis, has been a journey for me. A journey which I dedicate to those which I love the most, the persons which have taught me to find my path and which give me the inspiration to not stray from it.

This phase has also been a learning experience for me. I would like to thank my master project committee for the large amount of valuable guidance and support which I received from them. Alina and Andrei, the persons who were always there and which are very special for me. I am very grateful for the support received from my family and close friends. Not least I would like to thank Grontmij for enabling this research, organization to which I hope the research will further be very useful.
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Introduction

Building Information Modeling (BIM) is one of the most promising developments in the architecture, engineering and construction (AEC) industries. The benefits that it can provide make many organizations want to implement BIM and use it throughout their complex projects. However, this intention is not very easy to put in practice because of the novelty of the topic and because of the large complexity, that shifting from traditional processes to BIM implies. Figure 1 presents what sectors of the AEC industries facilitate their activities by using BIM. (Eastman, et al., 2011)

This graduation project intends to address the topic of implementing BIM within an organization and to look for solutions to make this endeavor a success. This work will be carried out with the support of the company Grontmij and more specifically of the Infrastructure projects department. The aims of the project will be to outline the view on BIM within the organization, identify the difficulties that shifting to BIM implies and set up a BIM implementation plan template specific to engineering organizations.

Figure 1 Building Information Modeling usage and connection within the AEC industry

The next chapter presents in detail the way the research is designed and the methodology used to reach the stated objective of the project.
2 RESEARCH DESIGN AND METHODOLOGY

2.1 Project Context

The first step in setting up a research design is to describe the project context, the problems related to this framework and the target within this problem context to which the researcher wishes to link. (Verschuren, et al., 2010)

This graduation project will address the subject of BIM implementation in an organization, trying to provide a structure for this complex process. The project being practice oriented was set up with the support of the company Grontmij and especially the Infrastructure Projects Section of the Wegen Department (part of the Transport and Mobility Division) at the office in De Bilt.

At Grontmij, BIM is at the start of its development, scattered initiatives taking place at the tactical and organizational level of the organization without a clear structure for use and collaboration. At the Wegen Department, these initiatives are reflected mostly in designing models in 3D without attaching other than graphical information to the model and without integrating the work of multiple disciplines in one model. The idea that BIM is one of the most promising prospects for the future design practices is clearly established and therefore solutions to implement it within the organization are searched for. Nevertheless there is no defined plan at the large scale of the company of how to make this.

From the academic perspective, this project is a master graduation thesis at the Master Construction Management and Engineering (CME) at the TUDelft and therefore will respect all the requirements associated. The research project will be designed as a practice oriented project, aiming to create a structured BIM implementation plan template for organizations, but with theoretical relevance by directly or indirectly contributing to a theoretical body of knowledge in the field.

The committee overlooking this project consists of academic and company members. The academic members of the committee are Dr. ir. M. J. C.M. Hertogh (Professor Design & Construction Processes, CiTG), Dr.ir. G.A. van Nederveen (Assistant Professor Design & Construction Processes, CiTG) and Dr. S. G. Lukosch (Associate Professor Systems Engineering, TBM). The members of the project committee representing Grontmij are ing. M.B.J. de Kroon and ir. J.W.Schokkin.
2.2 Project Objective

The objective of the master thesis is to identify the causes that make BIM implementation in engineering organizations challenging and to develop a template for a plan towards an optimized and structured implementation process. The first desideratum will be realized by providing an overview on industry specific implementation challenges and by providing a clear insight on the view and challenges identified within the commissioning organization, Grontmij Infrastructure Projects, and the second desideratum by analyzing the existing approaches and creating a BIM implementation plan template specific to the challenges identified.

The research objective is to create an insight and provide the valid information necessary to help the commissioning organization make the right decisions when implementing BIM within its structure. This objective is consistent with the prerequisites of an effective research: to be relevant for the organization and institute that enable the research, to be realistic in the sense that it is plausible to contribute to finding a solution for the problem that it addresses and feasible within available information resources and within the time scheduled.

2.3 Research Framework

The design of the research is practice oriented rather than theory oriented because it tries to find solutions for practical problems rather than develop new theories. There are five stages for a practice-oriented research (Verschuren, et al., 2010):

- Problem identification
- Diagnosis of the causes
- Design a plan
- Intervention and monitoring of implementation
- Evaluation of the result

As the project objective stated above includes both identification of causes and developing a plan, this research cannot be structured around one research type, but rather it will use both the diagnosis of causes and designing a plan frameworks.

Considering the scope and the time constraint of this research project, it will not go further than creating recommendations for an implementation plan and therefore will not reach the stages of monitoring and evaluating the actual implementation process.

Phase 1A: Problem Identification – Identify the current state and ambition with BIM

This stage will try to make clear what are the exact challenges for BIM implementation, why they are challenges and who is addressing them. By answering these questions, the research tries to identify what is the desired situation and point out the gap between the existing and this desired situation. The desired situation will result from the consensual common opinion of the stakeholders with regard to the description of the situation, which they explicitly or implicitly desire. This will take the form of a set of criteria, standards or tasks to be performed. This part of the project will support the further parts by identifying the exact challenges and by creating a consensus that will avoid setting the project inside an interplay of opposing opinions.
The input of information will be set up from two sources. The first consists of literature and theory review on BIM and its potential, technology implementation and organizational change, and challenges and background of causes of technology and BIM implementation. The second source consists of interviews with organization experts on current design practices, ambitions and intended use of BIM and perception related to expected challenges of BIM implementation.

**Phase 1B: Diagnosis of the causes – Define the causes for the BIM implementation difficulties**

In the moment when the problem is identified and clearly formulated the second phase of causes’ diagnosis can start. In this phase the possible antecedents, backgrounds and causes of the problem will be analyzed. A background analysis reflects on existing theories and antecedents while an opinion research looks for identifying the stakeholder’s perception of the causes of the problem. This information is used in an analysis of the gaps between the current and desired situation. The output of this phase will be in the form of a set specification of the desired results of the implementation process and a second set consisting of expected challenges and causes with BIM implementation within an engineering organization. These sets will be tested with a set of interviews with organization experts within an iterative feedback round.

**Phase 2: Develop BIM implementation plan**

The recommendations for an implementation plan should be created pertaining to the causes of these challenges defined in phase 1. In this sense, the plan will focus on the activities necessary to implement BIM within an organization considering the main challenges and their causes identified in prior phases, and will not focus on costs and schedules for these activities. Therefore the input information will consist of the one gathered in phase 1 as well as a second stage of literature review of literature and theory on technology and BIM implementation approaches. Functional (organizational, legal, etc.) and structural specifications should be fulfilled by the application of the designed plan. The functional requirements refer to the conditions that the stakeholders consider necessary for the implementation to fulfill in order to be successful and will result from an empirical research. The structural requirements are material and intangible characteristics of the intended model, which are necessary to meet the functional requirements and can be deduced from them. The information gathered throughout this phase will be tested within an iterative feedback set of interviews with organization experts.

Although the research will not evaluate the success of the implementation process, it plans to generate an evaluation tool that the organization can (at a later time) use to assess the success of the implementation process. This tool will be in the form of a multi-criteria analysis based on a set of criteria and weight factors in accordance to the specifications as identified and defined in phase 1 and on the results of consulting with the stakeholders. The scope is to test the level of satisfaction with the success of the intervention, this because usually an implementation manages to solve only partially the intended problems. It is good to specify that the research will limit to creating this tool and that applying it (chronologically this happens after the implementation process itself) will not be part of the research. Based on the results of this evaluation, the organization can choose to come back to an earlier phase to improve its results and so the implementation becomes a cyclic process. For the last part of the research, a set of criterion to
test the successful implementation of BIM within the organization will be set up in the form of a multi-criteria analysis.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weight factor</th>
<th>Level of satisfaction</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr.A</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Cr.B</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Cr.C</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td></td>
<td>ΣZ</td>
</tr>
</tbody>
</table>

Having set the phases of the project, the level of focus within the organization has to be decided. The research will give recommendations and focus most on the tactical level of the implementation, having connections with the strategic and organizational levels. The research will not focus on the technical aspects of the implementation of BIM.

Considering the objective of the research, the problem identification phase (1A) is a support for the further research and explains further the challenges that make the BIM implementation a difficult process. Starting from this point, in accordance to the research objective stated, the project’s focus will be on Phase 2 and Phase 3 and thus it will have 2 perspectives:

1. First the diagnosis oriented research, phase that will tackle the subject of the causes of the difficult implementation of BIM within the organization.
2. The second phase of the research will tackle the subject of developing a plan for implementing BIM into an organization.

In the figures below, the two phase of the conceptual model have been schematized:

Figure 2 Schematic representation of research framework - Diagnosis Phase
The 2 frameworks have the same structure based on the three consecutive levels of the research: the research perspective, the research analysis and the conclusions and recommendations. The research perspectives are based on a theoretical study (theoretical documents, standards and scientific practice that can assist in specifying the research perspective) and on empirical practical information formulated by meeting experts and stakeholders. The research analysis will be based on confrontation between the practical and theoretical (standards, theory and scientific practice) perspectives, so assessment of first based on the second. After each of the 2 steps an iterative step based on comments from the organization specialists will be set up in order to test the findings and provide feedback for refining the final version. From this interaction, the research conclusions and recommendations are drawn.
2.4 Research Questions

The research questions are meant to guide the project design and are in accordance to the research framework presented above. The main research question addresses answering the research objective and it can be effectively be divided into 2 questions linked to the 2 phases of the project (diagnosis and planning). The 8 sub-questions are intended to provide a more detailed insight into what information is necessary for successfully answering the research question.

What are the causes for the main challenges that influence BIM implementation within an engineering organization and what is the proposed set of recommendations for an effective BIM implementation plan template relevant to the commissioning organization?

1. What are the causes for the main challenges that influence BIM implementation within an engineering organization?
   a. What are the present and future main potential benefits for implementing BIM into engineering organizations as identified through literature review?
   b. What is the current practice and what are the intentions with BIM within the commissioning organization?
   c. What are the main challenges of technology implementation and what are the challenges and their causes for BIM implementation identified through literature review?
   d. What is the perception of the commissioning organization specialists related to expected challenges and causes for the implementation?

2. What is the proposed set of recommendations for an effective BIM implementation plan template relevant regarding the main challenges identified and the project context?
   a. What is an effective set of requirements that reflect the specifications from 1.b and tackle the causes identified throughout phase 1?
   b. What relevant recommendations related to the challenges identified can be extracted from literature review on technology implementation, organizational change and BIM implementation?
   c. What set of recommendations could be provided related to possible actions which outcomes’ converge to fulfilling the requirements from point 2.a?
   d. What is a good set of criteria and associated weight factors for a multi-criteria analysis regarding the successful implementation of BIM within the commissioning organization based on the perception of stakeholders?

The 2 leading questions have been developed based on the information that they refer to from the research framework, but also based on the type of knowledge that they intend to produce. The first question provides mainly explanatory knowledge, trying to discover what caused the problems. The second question provides prescriptive knowledge, giving recommendations for how the situation can be changed. A list of the links between each research question and the chapter or section where the answer can be found is presented in the Annex A of this report.
2.5 Research Strategy and Material

The strategy for this research project is based on the grounded theory approach, in which a specific plan is developed by starting with a wide view on the topic and systematically narrowing down this view on the specific problems in order to obtain a qualitative and depth research.

The perspective of the project is set up by analyzing the theoretical background on BIM and its implementation and related studies on technology implementation and organizational change. This analysis will be the commencing point of the research and will be carried out through a desk study aimed at identifying and extracting information from the most relevant studies on these topics. The sources of the information necessary for creating the perspective are libraries, industry reports and essays, and internet resources.

The main research object, BIM implementation, is extracted from a grounded research and the real situation at Grontmij Infraprojects. This will create an inductive comparison between the theoretical base and the experience with a real implementation case. This was preferred because the research is practice oriented and therefore, by combining the theory with a real implementation situation will result in a consistent output plan.

The first phase of the research uses the theory grounded perspective to assess the information obtained from the Infrastructure Projects Section (IPSG) of the Wegen Department at Grontmij. The grounded theory approach leaves room for flexibility and adjustability to the research for steering the direction of the second phase based on the findings of the first. The first phase combines the theoretical perspective with the information obtained from the implementation at Grontmij resulting in a set of implementation specifications and problems. Further, the second phase will use this input in an interaction with the theoretical concepts on technology and BIM implementations. From this interaction a set of implementation actions will be created in order to address the problems.

For both phases, regarding the sources and material used, this research is based on the triangulation of information method in order to create a consistent viewpoint. The main sources of information will be literature review of theory and standards, industry reports on BIM implementation and interviews with field specialists and internal reports. A scheme of the information used can be seen in the figures in section 2.3 of this report. The sources will be TUDelft library and internet for the literature review, digital documents provided by IPSG for industry and internal reports and semi-structured interviews with IPSG specialists. The list of specialist intended to be approached for the interviews can be found in the Appendix C of this documents. The persons considered for the interviews have been chosen based on their knowledge of the subject and on their interest and experience with BIM and its implementation.

The work will be carried out mostly from within the offices of IPSG in order to ease the access to information. The research will go from a breadth perspective for identifying the possible implementation challenges to a depth perspective when addressing the set of actions to deal with the specific ones identified. The research ends with a plan empirically constituted grounded on the information and insight gained throughout the process. A detailed table containing the material attributed to each stage of the project can be found in Annex B.
Introduction

This chapter is set up to form a good foundation point for the research by clearly defining BIM, presenting its main functions, the benefits that drive its adoption and the future prospects. A clear definition of BIM is presented in order to have a consistent meaning when referring to BIM throughout the paper and in this sense to avoid the possible confusions caused by the different meanings of the acronym, which is interchangeably used in literature for describing a process, technology or product. Starting from this point, the main functions of the technology are presented, in this way differentiating it from the traditional or other resembling design practices. Further the main benefits of BIM use are presented in order to understand the incentives for implementing it and for further reference when identifying the main drives of adopting BIM within an engineering organization. This is complemented with the presentation of the future vision for BIM in the context of being adopted by governments as mandatory practice and with tackling the possible future developments in the technology. Through presenting these aspects, this section aims to answer the research question 1a. *What are the present and future main potential benefits for implementing BIM into engineering organizations as identified through literature review?*

3.1 The need for BIM

3.1.1 Traditional AEC industry

The traditional process for delivering facilities in the AEC industry (further referred as industry) proves to have drawbacks, being fragmented and using two dimensional drawings modes of communication (see Figure 4). The fragmented industry, the continued paper based business practices and inconsistent technology adoption is considered to provoke estimated losses of $15.8 billion annually in the U.S. at the level of the year 2004. (Gallaher, et al., 2004) The errors and omissions attributed to this practice lead to increased costs, delays and lawsuits between the parties involved in the project.

One research conducted by the company Tardif, Murray & Associates (construction company from Canada) shows a good example of the complexity of the traditional industry practice in large projects. Counting the number of participants and documents in one of their projects they ended up with 420 participant companies (including all suppliers and sub-sub-contractors), 850 participant individuals, 50 types of documents generated which total up 56,000 pages. (Eastman, et al., 2011) This complexity makes such projects to be very difficult to be managed regardless of the contract types used.
Different solutions were searched for this situation and involved: design-build organizational structures, real-time web sharing of plans and documents, and use of 3D CAD tools. These methods have managed to improve the timely exchange of information but haven’t provided significant improvements to the severity and frequency of conflicts caused by paper documents or their electronic equivalents. One common problem associated with 2D-based communication during the design phase is the large amount of time and expense needed to critically assess the information from proposed designs (cost estimation, structural details, etc.). These analyses are usually done last when it’s too late to make important changes and this leads to the situation in which inconsistencies appear and compromises have to be made to the original design. (Eastman, et al., 2011)

Literature is abundant in presenting documented inefficiencies of the construction industry that can be associated with the current industry fragmentation and paper back communication. These are some recurring examples:

- The time and costs of projects are difficult to estimate correctly and control. (Smith, 2010)
- Litigations often occur due to inaccuracies and fail to reach targets (Smith, 2010)
- Changes are very costly and waste too much time (Laiserin, 2009)
- Duplicated data collection – information is not passed on fluently during the project lifecycle (Smith, 2010)
- Not enough collaboration during designing and construction processes (De Ridder, 2011)
- The labour productivity has stagnated in the past 50 years in the AEC industry, compared to the average of other non-agricultural industries which have doubled their productivity. (Teicholz, 2007)
• The facilities use very much energy, 71.8% of the total U.S. electricity production is consumed by nonindustrial buildings. (Smith, et al., 2009)

• The construction industry generates more than twice the waste than the manufacturing industry (Eastman, et al., 2011). The Construction industry Institute estimates that up to 57% of the construction industry spending is non value added or waste. (Diekmann, et al., 2004) (see Figure 5)

![Figure 5 Construction – Manufacturing Waste Comparison (Smith, et al., 2009)](image)

3.1.2 **Relation to other industries**

The need to control information and develop it through iterative design processes until the manufacturing phase has been recognized in other industries as well. The manufacturing and industrial design industries have been driving the software companies to develop programs capable to parametrically control, modify and test manufacturing pieces before producing them. This practice is named digital prototyping and brings great benefits in decreasing the time and costs spent modeling and testing prototypes which later are mass produced.

BIM is based on the same concept but at a much larger scale. It came into the attention of the AEC industry in order to address the same needs but some differences made the actual adoption slower. The main differences consist in the scale of what was to be modeled which was beyond the capability of the existing software. There weren’t any tools to efficiently model buildings, also any computers powerful enough (at reasonable prices) at that time to run these models. Moreover the unique designs each time made it difficult to recover the cost of modeling the building through mass production. (Zyskowski, 2008)

More industry-specific characteristics have made it difficult to make this step. Alterations and reconstruction works represent 23% and the maintenance 11% of the construction volume. These type of work rely mostly on labor intensive work methods and most likely to remain so. Therefore 64% of construction represents new work. Another aspect is the fragmented adoption of new technologies. Mostly large companies are the (only) ones adopting new and improved business practices. This results in the necessity to often revert back to paper or 2D CAD drawings to allow communication with all the project team members and to keep the range of possible contractors and subcontractors as wide as possible. This has prolonged the use of paper communication methods in the industry in the past. (Eastman, et al., 2011)
3.2 Definition of BIM

3.2.1 Creation of BIM

Historically, as a solution to inefficiencies in the AEC industry and inspired from other industries, BIM has been conceptually created in the 1970’s. The first implementation of this concept was the virtual building concept by Graphisoft’s ArchiCAD which debuted in 1987. Since then more software companies (Autodesk, Bentley Systems) developed alternative BIM design capable software. The actual term of Building Information Modeling (BIM) first appeared in 1992 in a paper by van Nederveen et al. and has been adopted throughout the industry since. A schematic representation of the concept can be observed in Figure 6. The AEC industry practically started to use it in projects from the mid-2000s (Azhar , et al., 2012)

![Schematic diagram of BIM concept](image)


3.2.2 Definition

A commonly accepted definition of BIM is: “Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.” (U.S. National BIM Standard - NBIMS)

With BIM technology, a virtual model of a building’s spatial, physical, quantitative and qualitative characteristics is created. This model is used to facilitate cooperation between the different parties involved in the project, thus supporting the project through its lifetime in the design, construction, fabrication, procurement and maintenance phases (see Figure 7). This approach allows better analysis and control than manual processes. Thus, it provides benefits by offering a better integration for the project’s processes that results in a better quality building, provided at lower costs and with reduced construction duration. (Underwood, et al., 2010)
3.3 The main functions of BIM

Building information modeling is an innovative approach to building design, construction and management that is characterized by the continuous availability of highly accurate, consistent and reliable building information. BIM allows the project team to visualize, simulate and analyze a project before construction even begins using a 3D model representing all of the physical and functional characteristics of a facility. (PCI, 2009)

BIM offers a structured information model, database, and intelligent building objects and describes the whole design. It consists of object, relations between objects, attributes, parameters, consistency, views and provides work-sharing capabilities. All these contribute to having: less design and construction errors, fewer errors in data, lower cost, faster building, reuse and share of data, advance insight due to simulations, a better understanding of options and associated costs, more and better information early in the design, consistency in drawings and better control of the process and the production. (Underwood, et al., 2010)

3.3.1 Resembling but not BIM

Now that BIM has been defined it is good to look at what features a BIM model actually possesses. There are a lot of software solutions and design processes that promise to be BIM capable, but they are not. This includes modeling solutions that create: models that contain only 3D data and no object attributes; models with no support of behavior (that don’t use parametric intelligence, defines objects but cannot adjust their positioning and proportions); models that are composed of multiple 2D CAD reference files that must be combined; models that allow changes to dimensions in one view that are not automatically reflected in other views. (Weygant, 2011)
3.3.2 Features of a building model

The research of Eastman, et al., 2011, identifies the main features of BIM that differentiate it from traditional construction design practices.

a. Components are represented with digital representations (objects) recognizable by software applications and with intelligent manipulation due to parametric rules
b. Components include data that describes how they behave (required for analyses and work processes)
c. Data is consistent and non-redundant. Such that changes on one components are represented in all views of that component as well as the assemblies of which it is part

3.3.3 Parametric objects

Modeling based on parametric objects is a major change in the industry that facilitates the change of the workflow in design from drawing based towards digital models able to create consistent drawings, schedules and data. (Laiserin, 2009)

One of the main differences comes from a different way in which the BIM design software functions compared to the traditional CAD. The BIM software is based on the concept of parametric objects in which each constitutive element of a building has boundaries in the form of the objects that border it. The way objects are connected determines their shapes in all layouts. Global parameters as grids can also be used to define the propagation of a change through a model. Therefore, designing a building that contains a hundred thousand or more objects would be impractical without a system that allows for effective low level automatic design editing. Adding these shared parameters to the shapes in a design has clearly differentiated BIM from traditional 3D objects. The main characteristics of a parametric design are, according to Eastman, et al., (2011):

a. It consists of geometric definitions and associated data and rules.
b. The integration of the geometry is non-redundant and doesn’t allow inconsistencies.
c. Parametric rules determine automatic modifications of associated geometries when changes are made to associated objects
d. Objects can be defined at different levels of aggregation. Any change in a subcomponent determines a change in the higher hierarchical levels.
e. Rules for objects identify when a change violates object feasibility (size, manufacturability, etc.)
f. Objects have ability to link to, receive or export sets of attributes to other applications and models (structural materials, energy data, etc)

In a parametric design, instead of designing first a building element, first is defined an element class which consists in a mixture of fixed and parametric geometry and a set of relations and rules to control the geometry by which element instances can be generated. The shape and geometry in a parametric modeler automatically adjusts to changes in context and to high level user controls, editing based on the rules used to define it.
The main information content that a BIM object can have attached are:

d. Geometry

e. Material specification – name and texture

f. Parametric geometry, if not fixed

g. Location of connections and requirements for: structural, electrical, plumbing, telecommunications, and ventilation systems.

h. Performance specifications, operating life, maintenance cycle and other specifications.

i. Product distribution links.

Nevertheless, a BIM model can also contain objects that don’t behave parametrical and don’t vary with the context, for example objects from different producers that have fixed dimensions and are used as they are. They are called object models and they are more easily created and also more widely available in external web libraries.

3.4 Benefits for using BIM

Whenever large investments and modifications to project conduction are required, the advantages that the change brings have to be substantial in order to be worthwhile.

BIM is increasingly becoming regarded as the future of designing and managing for large construction projects. (NBS, 2013) This is the result of the better acknowledged benefits that BIM processes bring to architects, engineers, owners, facility managers, contractors, subcontractors and fabricators. This subchapter will analyze these potential benefits for each phase of a project along with the future prospects of BIM technology.

3.4.1 Benefits for owners and project management

The owner of a facility and the project management are the ones that have the highest influence on deciding whether or not to use BIM for a new project. Many projects are beginning to use a different set of contracts, specifications and project requirements in order to incorporate the BIM processes and technologies. This happens because BIM use has proven to bring advantages in the market for the owners of a project by delivering higher value projects with reduced operational costs. Further these potential advantages will be presented.

3.4.1.1 Better assessment of project design and options analysis

At each stage it is essential for the owner to be able to verify that the project is within the ranges of his scope. These requirements can be spatial, functional, or of other natures.

Traditionally this process is performed by assessing the drawings, images and renderings provided by the design team. But assuring that all requirements have been met using this procedure is difficult, even more when these requirements change after the initiation of the project.
BIM provides a good way to address this issue. Its visualization capacity is an improvement for communicating with all involved stakeholder, re-adjusting their requirements and inputting feedback. More, with BIM, cost estimates and feasibility studies are more easily performed and can be done at an earlier stage. This along with the possibility to rapidly reconfigure and explore new design options gives helps in taking decisions that fit better with the set of stakeholder requirements. (Azhar, et al., 2012)

3.4.1.2 Increased collaboration and mitigating litigations

The coordination and collaboration processes are sustained by working with BIM especially in the part regarding accountability and litigations between project participants. The situation in which litigations appear regarding who is accountable for a design change, assuring that the requirements and scope are met or lack or responsibility of inappropriate project information and documentation can be improved by using a BIM design process. The collaboration that it involves to create the building model between the project participants can often lead to better accountability and increased responsibility between the parties. (Conover, et al., 2009)

3.4.1.3 Cost estimation tool

Most of the construction projects report cost overruns, according to the study of FMI/CMAA (FMI/CMAA, 2005, 2006) more than 2/3 of construction projects experiencing this problem. Therefore the reliability of the cost estimates is a very important factor in decision making especially at the beginning phases of a project because this is the stage when the ability to influence costs is the greatest (see Figure 8) (Eastman, et al., 2011).

![Figure 8 Ability to influence costs during project lifecycle](image)

Improving cost reliability is a good motivation for using BIM based cost estimation because of two advantages. One is that the estimations are more reliable due to the information useful for estimation attached to the model and the second one is that the estimation process can take place earlier in the process. Quantity takeoff tools available for BIM are providing a fast way to make
these analyses and therefore can be used to provide cost information at an early stage for different design alternatives. The owner can thus take better decisions on design alternatives and assess better the budget required for a project. Nevertheless, the BIM-based cost estimation and quantity takeoff tools are just complementary to the skills and experience of cost estimators who have knowledge to assess the cost uncertainties related to unexpected situations and market development. (Conover, et al., 2009)

3.4.1.4 **Increased data value and improved data transmission**

In the traditional building process, there are several stages for transmission of building data. These stages provide discontinuity in the data transmission which can be translated into a loss of value. For example, transmission of the data from designers to construction teams to building operation are all accompanied by data loss which brings added costs to reconstitute the data and loss in data integrity.

A study made to estimate the losses in the capital facility industry in the U.S. ((NIST and Fiatech, 2006) has shown that in 2002 the annual cost related to insufficient interoperability between CAD, engineering, and software systems is approximated at $16 billion. Further, 2/3 of these costs are supported by the owners and operators. Moreover, there is also the issue of data quality that is or not worth sharing in some cases. BIM provides coordinated, consistent, and computable information about a building project that doesn’t face this issue. (PCI, 2009) A good representation of the data loss in these transitions made throughout a facility lifecycle and the increase in value of the data through a BIM process (Figure 9) is given in the research of Eastman, 2011.

![Figure 9 Data value in facility lifecycle (based on Eastman, et. al., 2009)](image.png)
3.4.1.5 Reduced time to market

Reducing the time in which a construction project can be finalized and brought to the market reduces the risks associated with the market fluctuations and increases the profitability by gaining revenues from a facility faster.

BIM technology can contribute to reducing the time to market of a facility in different ways. One is that parametric modeling can be used to automate partly the design process and to decrease the duration of design changes (see 3.3.3). Secondly, prefabrication is a mean to increase productivity and decrease project durations, and BIM can be used to rapidly export design elements to prefabrication sites and to coordinate this process. Thirdly, BIM has 4D model capabilities including time scheduling tools which provide better monitoring of activities and also better planning capabilities. (Kymmell, 2008)

3.4.1.6 Tools to assess energy use and sustainability

Sustainability and energy consumption is an increasing important characteristic for buildings from the facility management perspective. Operational costs can represent a large part of a facility’s costs throughout its lifecycle, in some case up to 80%. There are several BIM tools capable of assessing energy use of a building. This provides large benefits when choosing design alternatives that improve energy consumption and maximize energy use. (Conover, et al., 2009)

3.4.1.7 Facility asset management

A building model can be used also as a facility asset management tool during the exploitation phase of a project. The owner can view the facility’s condition, manage and plan maintenance or assess the impact of retrofit work. (Eastman, et al., 2011)

All the above enumerated capabilities of building models are based on the assumption that the service providers that create the models are assuring them adequate scope, level of detail and attach the required information.

3.4.2 Benefits for designing and engineering

At the designing level, changing to BIM can bring large benefits but also comes with some costs. These costs refer to an increased collaboration necessary for decision making, more effort in developing the set of construction documents and assembling the information and of course the investment necessary to change the work method to BIM. The forward paragraphs will bring examples of benefits brought by BIM to the design process that should justify the added costs.
3.4.2.1 Design effort concentrated in the beginning of the process when changes can be made more efficiently

The BIM process of design requires more of the design effort during the initial parts of a project. This is also the time when changes can be made to the design with less costs. This situation can be represented best graphically (see Figure 10).

![Figure 10 Ability to impact design changes with BIM and traditional designing (based on Patrice MacLeamy, CURT (2007))](image)

This figure presents the added value of designing with BIM through the increased capacity to control the costs of a project. In the same time this also involves the parties to collaborate and take project decisions more in the beginning stages of a project, fact that consequently involves a different contract relationship. See Annex D for effort distribution of BIM effort per project phase based on research of Napier, et al., 2009.

3.4.2.2 BIM as clash detection and analysis tool

BIM technology allow for clash detection software to check for inconsistencies in the design check which aims to assure feasibility for the design. These features are value adding directly to the quality of the design process and very important incentives for adopting BIM because of their direct costs reduction capabilities.

Due to the possibility of using the model as basis for analysis for structural, energy, safety or simulation tools, BIM also reduces the time of conducting these analyses. This feature is increasingly beneficial when the model is constructed as to comply with the requirements of the analysis tool, both as geometry and as exchange format.
The building model can also be used to support accurate bills of quantity output, costs estimations tools and scheduling applications. These are very useful tool for the design process as they can help in gradually tuning the design to fit the designated construction costs rather than estimating and amputating it at the end.

Simulation tools are also available for BIM models. With them analysis of building behavior for operations or emergency situation can be made during the design phases.

### 3.4.2.3 Automatic and consistent drawings

Each object instance is represented only once with BIM. This includes the shape of objects, the properties and its location within the model. Due to this feature, all drawings, reports and datasets can be extracted in a non redundant and thus consistent mode.

This property of building models solves on its own an important source of errors typical to 2D drawing designing where the changes and edits have to be represented on new drawings which sometimes are not consistent with the previous versions due to human errors or omissions.

BIM also allows outputting automated drawings of different 2D or 3D views from the model, reducing thus the cost of drafting each 2D drawing individually and also reducing the possibility of inconsistencies associated with it. Along with this, there are BIM software which allow for direct fabrication drawings to be exported to fabricators and installers. (Leicht, et al., 2011)

### 3.4.2.4 Synchronization allowing for unique model

The goal for BIM servers is to become locations where the models can be stored, exchanged and, most importantly updated with project synchronization (see Figure 11). Project synchronization is a very important feature for BIM because it means that all the project files worked on from different users are brought together consistent with one another to constitute a nonredundant model. At this development point of BIM technology, the synchronization is not yet fully automated due to the design decisions required to make revisions for consistency. Therefore human management still represents a part of the synchronization process and, for the moment fully automatic synchronization is not possible. The objects are carrying timestamps (information about by whom and when was the object last updated) and global unique IDs (GUIDS) for individual identification. This information about the data is called metadata and is important for managing the changes done to objects in time and for achieving the automatization of synchronization and clash detection. (Leicht, et al., 2011)
3.4.2.5 Forwarding know-how

The parametric object classes are developed by the software companies that provide the BIM software and by other associated software companies that work together with industry groups and experts to enlarge the library of object classes. Some BIM software allow for the users to develop their own object class and therefore personalize the software based on their own requirements. This is a very useful capability especially for companies that repeatedly deliver the same type of specialized work and that want to introduce their earned work experience into their parametric design capacity. In this way the companies can embed knowledge based on past efforts on design, production, assembly and maintenance based on what works and what doesn’t and fine tune it in time.

3.4.3 Benefits for construction

Construction has also benefits through using an accurate building model that reflect in saving money and time for the project. They are results of a better planned construction process and reduction for errors and conflicts. Further in this subchapter the potential benefits for construction will be presented.

3.4.3.1 Integration of the design and construction processes - early involvement of contractor in the project

The better integration of the design and construction processes brings advantages to both. It is based on an earlier involvement of the contractor and its subcontractors and fabricators in the project when the BIM model is constituted. This allows them to provide more of their knowledge to the project earlier when design changes are more facile. This shortens the procurement schedule, increases the value of the design by allowing modifications to be integrated fully into design. More it allows for insight from the contractor and fabricators to increase constructability.
and reflect best practices, facilitates identification of construction limitations, avoids inconsistencies from fabrication manufactory and fastens the fabrication detailing and reduces coordination errors during construction through review and project tracking based on the model. IPD (Integrated Project Delivery) implies that in a joint contract, the designer, architect and main contractor work together from the beginning of a project BIM can be best used as a collaborative tool during the initial phases.

3.4.3.2 Clash detection used to prevent design errors

Automatic clash detection tools are very useful to identify accurately design errors which otherwise would have to be identified through a prone to error manual process. Clash detection is able to identify “hard clashes”, objects occupying the same space and “soft clashes” when objects don’t have adequate access, safety measures, insulation or maintenance for example. In order for a clash tool to identify soft clashes, the program requires the BIM user to insert component classification and conditions and thus create a detailed and well defined building model. This requires the team members to increase collaboration in order to accurately introduce the information that relates to their responsibilities and to find and manage design errors.

3.4.3.3 Cost estimation tools

As presented in the subchapter 3.4.1, BIM tools for quantity takeoffs and cost estimating facilitate interim cost estimations. The benefit comes in the shape of facilitating the laborious task of quantity takeoffs and thus for up to date cost estimations. The Stanford University Center for Integrated Facilities Engineering (CIFE) has statistic result from 32 projects using BIM and concluded that the use of BIM reduces time necessary to generate cost estimates by 80%. (CIFE, 2007). This gives room for finding problems sooner and considering alternative solutions when changes are possible in order to meet the cost restraints. The contractor can benefit from this by mitigating risk associated with cost bidding, increasing the reaction speed in relation to changes during the phases of the project and optimizing prices from subcontractors and suppliers.

3.4.3.4 Construction planning and coordination

Gantt chart is usually the method of representing project schedules, a representation without clear visualization and therefore requires a good knowledge of the project in order to be able to assess if the schedule is feasible. BIM allows schedulers to create 4D models linked to 3D geometry that allow for visualization of the sequential construction phases. This enables schedulers to visually plan activities in context of space and time and communicate with other project team members through 4D schedule simulations. Resource utilization attribution is also possible through BIM tools for project scheduling. The main benefits are the enhanced communication between team members and stakeholders, the enhancement of site logistics, which gives incentives for avoiding bottlenecks and for a better project coordination. (Kymzell, 2008)
3.4.3.5 Offsite fabrication use

Offsite fabrication usually reduces labor costs and onsite installation risks. BIM tools allow the contractors to communicate BIM component details directly to fabricators, with information about geometry, materials specifications, finishing requirements and delivery sequence. The benefits come from the reduced times related to verifying and validating the orders due to the accurate BIM information. (Kymmell, 2008)

Results from an analysis performed by the Stanford University based on 32 major projects using BIM have indicated direct benefits. Up to 40% elimination of unbudgeted costs, cost estimation accuracy within 3%, up to 80% reduction in time necessary to generate a cost estimate, savings up to 10% of the contract value through clash detection and up to 7% reduction in project time. (CIFE, 2007)

Concluding, the main advantages of using BIM are to increase design speed and accelerate construction, avoid design mistakes, achieve higher precision and flexibility, improve cooperation between partners, connect to analysis and simulation software and provide a “file to factory” parts fabrication system. (Welman, 2012). Table 3 presents a summary of the benefits.
### Table 3 Summary of BIM benefits for each project phase

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Project Phase and Effects</th>
<th>Project Management and Operation</th>
<th>Design and Engineering</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Improved visualization</strong></td>
<td></td>
<td>Better assessment of design alternatives and improves stakeholder communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Earlier and increased collaboration</strong></td>
<td></td>
<td>Increase in team members responsibility and mitigating litigations</td>
<td></td>
<td>Enables contractor’s experience to influence the design model and thus increase value</td>
</tr>
<tr>
<td><strong>Design effort concentrated at the beginning of the project</strong></td>
<td></td>
<td>Increased capacity to make cost effective design changes for assuring project feasibility</td>
<td>Increased capacity to make cost effective design changes for assuring project feasibility</td>
<td></td>
</tr>
<tr>
<td><strong>Automatization of design clash detection tools</strong></td>
<td></td>
<td>Reduced time to market</td>
<td>Increased consistency and design speed</td>
<td></td>
</tr>
<tr>
<td><strong>Analysis tools compliance and code review</strong></td>
<td></td>
<td>The model can be used by official bodies to review and grant permits.</td>
<td>Increase designing speed through one time drafting the model</td>
<td></td>
</tr>
<tr>
<td><strong>Synchronization of model</strong></td>
<td></td>
<td>Non-redundant model and increased design team collaboration</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Customization of object classes</strong></td>
<td></td>
<td>Enables forwarding of company know-how</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cost Estimation Tool</strong></td>
<td></td>
<td>Facilitates decision making based on reliable estimates earlier in the process</td>
<td>Enables designer to gradually assess the financial feasibility of his design</td>
<td>Improved cost biding and reaction speed to project changes</td>
</tr>
<tr>
<td><strong>4D planning and coordination tools</strong></td>
<td></td>
<td>Improved communication within project team</td>
<td></td>
<td>Improved communication within project team and stakeholders and avoiding bottlenecks</td>
</tr>
<tr>
<td><strong>Increased offsite fabrication</strong></td>
<td></td>
<td>Reduced time to market</td>
<td></td>
<td>Increase accuracy and speed of data exchange</td>
</tr>
<tr>
<td><strong>Energy use assessment tool</strong></td>
<td></td>
<td>Reduced operation costs and increase sustainability</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Information database for specifications and maintenance</strong></td>
<td></td>
<td>Improved facility management</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Data transmission method</strong></td>
<td></td>
<td>Increase in project data value avoiding phase transitions data loss</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.5 Future vision for BIM

This section intends to address the future of BIM as it can be foreseen today from two perspectives, short term development and long term vision. The short term development start from the current benefits of using BIM and try to identity how the market and especially governmental bodies (re)act to incorporate BIM use within their practices and requirements. The long term vision is mostly focused on the future potential benefits of BIM technology taking into account the development of software and hardware technology and the increasing use of BIM. Nevertheless, this will not be presented broadly as the information available in literature is mostly of speculative nature. Further we present a statement from a construction industry analyst representing a strong positive attitude towards adopting BIM.

“BIM will reshape the industry, it is not a question of if, it is a question of when. Those who feel that the boat is doing just fine and should not be rocked may find themselves scrambling for BIM once it becomes a general requirement.” (Jerry Laiserin, industry analyst)

The main drives towards this change are the benefits presented in the previous subchapter. The expectations for the short and medium term for BIM are especially towards a broad industry adoption. The findings of the national BIM survey in the UK (NBS, 2013) have shown that 94% of the respondents (design and construction specialists) expect they will use BIM until 2016.

Several government bodies have started to acknowledge the benefits of using BIM and to take on a proactive attitude to create ambitious strategies that will capitalize the success and take on a global leadership role in BIM exploitation. Their tool in this endeavor is requiring BIM data models for code checking and design reviews. The most advanced in this sense are the initiatives of the UK, the state of Wisconsin in the USA and Singapore. (Eastman, et al., 2011)

The UK program on BIS BIM Strategy targets creating a program that will enable a fully integrated BIM milieu for companies with potential untold benefits. The main feature of this strategy is the requirement of fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum for large public projects starting from 2016 (see Figure 12). The level 2 BIMs should contain architectural, structural, facilities, building services and bridge information models. (UK Government Construction Strategy, 2011)

This situation has driven an fast increase in the interest for adopting BIM within the industry’s professionals. The statistics support this statement. The level of BIM awareness has increased from 57% in 2010 to 84% in 2012 and the level of BIM usage from 13% to 39% in the same period. (NBS, 2013)
In the USA there are also efforts similar to the ones in the UK. An example is the Wisconsin Department of Administration which has made the BIM guidelines and standards mandatory for public new projects larger than $2.5 mil and for public addition projects larger than $5 mil since July 2009. The National BIM Standard is also increasingly used and adopted, without mandatory character. Concerning the use of BIM through USA’s AEC industry, surveys reported that 28% of industry was using BIM in 2007, level which increased to 49% in 2009, 42% of which considered themselves as experts or advanced users of BIM with contractors being the fastest adopters.

In the Netherlands, government bodies have also turned their attention towards BIM. Rijksgebouwendienst (the Government Buildings Agency) and Rijkswaterstaat (the Government Infrastructure Agency) look to influence the market towards BIM in order to improve their asset and stock management, reduce failure costs, improve management in the supply chain and increase efficiency especially in the operation and maintenance phases of a project. The Rijksgebouwendienst has developed the Rgd BIM Norm, a set of standards aimed to regulate the specifications of BIM extracts and accompanying deliverable files that it requires, and has started to include it in new contracts since 2011. (Rijksgebouwendienst , 2012 ) Rijkswaterstaat’s vision is also matching well with BIM, as RWS desires to manage the vast information that is possess in an efficient way and to use it for steering the market processes. Digitalization can provide great benefits in this sense. That is why RWS has also developed ways to incorporate BIM into its projects and specifications for best use practice. (Wim Verbruggen , 2013 )

The trends related to processes and technology show that owners are increasingly demanding BIM and changing contract terms to enable its use. Among professional new skills and roles are developing along with a constant increase in the proportion of users. Further, the benefits of integrated work practices are receiving wide reviews and intensively tested in practice which
leads to development of standards. The technology is also advancing along with the advance in usage providing more automation capable and increased functionality towards richer BIM platforms. Further, discipline specific BIM tools are increasingly appearing and product catalogues are beginning to be offered in parametric 3D versions by manufacturers. Therefore it can be seen that BIM is becoming increasingly and intensively a mainstream practice. (Eastman, et al., 2011)

Designing and engineering companies will be impacted by BIM by shifting services and roles and it is expected that a vast majority of them (80-90%) will have worked on projects using BIM in the next five years. The main drives for adoption will be client demand for enhancing quality of service, productivity gain in preparing documentation and contractor demand to support virtual construction. Furthermore, along with the internal advantages described above, the competitive advantage that BIM provides will be the external motivation for gaining a good market position. On the other hand, this change will require a shift in the quality and nature of the services towards performance based designing by using tools to better inform the design decision rather than just relying on experience. The scope of the services provided by design companies will be broadened by including detailed energy and environmental analyses, operations analyses with facilities and value engineering relying on BIM driven cost estimation during the design process. These and further more possibilities will initially differentiate the companies capable of such services on the market. The roles of the designers and engineers is also expected to change towards a decrease in staff dedicated to document producing activities and appearance of a new role of model manager with integrated design and technical knowledge. (Eastman, et al., 2011)

For the long term, the expectations for BIM are about what it can become. The vision is that it should be “a planning, design, construction, operation and maintenance process using a standardized machine-readable information model for each facility which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle”. (NBIMS)

The long term vision for BIM is based on the predicted further developments in software and hardware technologies, internet, societal change and other less predictable forces. BIM should become an easy and reliable information source. A cross linked BIM/GIS platform capable of offering everything from high level GIS information to detailed BIM information, bridging the gap between world scale and detailed data. The long term vision also incorporates increased productivity achieved through higher efficiency from captured knowledge, optimized communication, ongoing work process analysis and change and more. Reduced project risks is also a long term goal for BIM, based on improved information quality for project planning, increased transparency in decision making, optimized facility design and management and accurate assessment of project goals. (Napier, et al., 2009)

As this subchapter suggests, the review on BIM’s future and future potential enables us to predict a high future adoption rate within AEC industry based on the high current and potential benefits and gives reasoning to view BIM as an update rather than an alternative work practice.
3.6 Conclusions

Chapter 3 has focused on creating a theoretical background for BIM, accumulating information regarding what is BIM, how it differentiates from other related work practices and what are the current benefits that drive its adoption as well as its future potential.

The results of this endeavor were in the form of a clear definition of BIM, along with a brief presentation of the main functionalities that a model should have in order to be considered a BIM model. In short, BIM is a digital representation of physical and functional characteristics of a facility. The elements composing this representation are recognizable by software applications capable of intelligent manipulation and analysis due to the parametric behavior of the elements and to the non-redundant and consistent data. BIM use leads to large benefits for clients, designers, engineers, contractors and the rest of parties involved in the lifecycle of a construction project. A comprehensive list of the benefits for adopting BIM has been set up by performing literature review and linked to the actors that make direct use of each of the advantages. The main benefits come in the form of support for the entire length of the project, facilitating increased collaboration, design alternative selection, cost and time control, creation of a centralized information database, avoiding data redundancy and limiting design inconsistencies. Finally, a presentation of the developments towards BIM adoption throughout industry has been presented in different international contexts and complemented with the long term vision of industry specialists regarding what BIM will become.

The information presented in this chapter will form the foundation for the further chapters, which are focusing on the implementation process, by clearly defining the subject of the research and by clearly setting the incentives for its adoption.
Introduction

Having presented a comprehensive overview on the benefits that the adoption of BIM technology can provide to an organization, the further step is to present theory that provides guidance for the implementation process. This chapter aims to answer research question 1c - *What are the main challenges of technology implementation and what are the challenges and their causes for BIM implementation identified through literature review?* The answer will be formed in this chapter by reviewing the current theory on technology implementation at organizational level and project/individual level, relevant for the construction industry. From this perspective, the chapter will provide a thorough insight into the theoretical challenges that the implementation process of BIM faces. These theories will be integrated into a framework that will be used in the next chapter to analyze the practical case of BIM implementation within an engineering organization.

The implementation theory regarding innovation and technology adoption will focus on both organizational and individual levels due to the different mechanisms that influence the adoption process. (Oliveira, et al., 2011) Nevertheless, the adoption mechanisms at the two levels are complementary and interconnected, and this research will present both but focusing on the organizational level implementation. While the organizational adoption theory will present from a broad perspective on technology range due to the similarities at this level of adoption, the individual level will be presented in the context of ICT use by actors in construction projects due to the specificity of this technologies at individual use level. The first and most general theory that will be presented is the broad innovation diffusion theory. From this viewpoint, a specific innovation adoption will be tackled, technology, through the TOE (technology, organization, environment) framework. The two theories will be set up into a common framework that separates factors of the environment, organization and innovation and links them to the strategic, tactical and operational level decision making. This framework will constitute the base for analyzing technology implementation at organizational level for the case study. Further the research will focus on the theory of Arjen Adriaanse which addresses ICT adoption in construction projects at actor level, thus describing the mechanisms that influence adoption for individuals and small teams. This as well will be introduced into the common framework and later be used to analyze the individual level adoption of ICT. The last part of this chapter will focus on the theoretical challenges of BIM implementation. This will be carried out through a broad literature review and the resulting challenges will be structured through the common framework and linked with the mechanisms of the theories on technology implementation.

Through researching the theory on technology implementation and main challenges for BIM implementation, this report has a good base for analyzing the practical case of implementing BIM within an engineering organization and for setting up the template for the BIM implementation plan which is the final objective of this research project.
4.1 Technology implementation theory

4.1.1 Innovation adoption - Diffusion of innovation theory (IDT)

Diffusion of innovation is the process through which new ideas, concepts, technology, technical information and actual practices are spread from a source to an adopter, usually via communication and influence. At industry level this is the process through which innovative technology (as BIM) is being spread. (Straub, 2009)

The innovation diffusion theory (IDT) is arguably the most influential theory for understanding how, why and at what rate an innovation spread through cultures, operating at the individual and organization levels. This is a broad theory providing a comprehensive structure for understanding particular, adoption and collectively, diffusion. The IDT theory was developed and extended by multiple studies and is based on the work of Everett Rogers, *The Diffusion of Innovations*. This theory is the fundamental groundwork synthesis of adoption-diffusion literature across disciplines. (Straub, 2009) This is the reason why it has been chosen as a starting point for creating the theoretical framework of this research.

The diffusion of innovations in organizations is complex, generally involving in the decision making process individuals which can be supporters but also opponents of the new idea. The IDT theory describes 5 stages in the process of adopting an innovation. (Rogers, 1995)

1. Stage 1 is becoming aware of the innovation. This is influenced by the characteristics of the adopter, socioeconomic factors and access to change agents.
2. Stage 2 is persuasion, the process of gaining knowledge about the innovation characteristics and making a judgment that leads to a favorable or unfavorable view on the innovation.
3. Stage 3 is decision making, choosing either to adopt or reject an innovation. In organizations, the adoption decision can be either collectively made or authority imposed. Usually there are certain individuals termed “innovation champions” which stand behind an innovation and break through any opposition that the innovation might cause.
4. Stage 4 is implementation, acting on the decision.
5. Stage 5 is confirmation, reflecting on the decision made and implementation process and re-evaluating either to continue or stop the innovation adoption.

There are multiple factors that influence the timing of the 5 stages of adopting an innovation for an organization based on the IDT theory. These factors have been divided into 2 groups of independent variables. These are: the characteristics of the organization and the characteristics of the innovation. These characteristics presented further were researched by Rogers (1995) and adapted according to the integrated model of Wejnert (2002) (adding relative position in inter-organizational network to the external characteristics of the organization).

1. Characteristics of the organization – organizational innovativeness:
   Individual (leader) characteristics:
   1. *individual (leaders) attitude towards change*: the predisposition of the individuals to adopt innovations and do it faster/slower than others
**Internal characteristics of organizational structure:**

2. **centralization**: the degree to which power and control in a system are concentrated in the hands of relatively few individuals

3. **complexity**: the degree to which an organization’s members possess a relative high level of knowledge and expertise

4. **formalization**: the degree to which an organization emphasizes its members’ following rules and procedures

5. **interconnectedness**: the degree to which the units in a social system are linked by interpersonal networks

6. **organizational slack**: the degree to which uncommitted resources (financial and human) are available to an organization

**External characteristics of the organization:**

7. **systems openness**: direct, vicarious or observation based communication processes and transmission of information

8. **relative position in inter-organizational network**: prominence within the network relative to level of heterogeneity of the network (horizontal and vertical position within network structure)

2. Characteristics of the innovation:

1. **relative advantage**: benefits versus costs (monetary and nonmonetary, direct and indirect costs and associated risks versus the benefits) and public versus private consequences (the impact of an innovation’s adoption on entities other than the actor)

2. **compatibility**: congruency with organization’s work practices

3. **complexity**: perception on comprehension difficulty

4. **trialability**: how easily an innovation may be experimented, direct or vicarious testing

5. **familiarity**: observability and visibility of innovation to adopter and its network

The characteristics presented above influence if and how fast an organization adopts innovations. The research of Rogers (1995) presents the function of the population of actors adopting new innovations as an S-curve, having a normal distribution over time. The distribution can be divided into 5 categories of adopters based on the speed to incorporate innovations: innovators, early adopters, early majority, late majority and laggards (see Figure 13).
The IDT theory describes how, why and how fast innovation adoption occurs but does not describes how to facilitate adoption, being descriptive theory rather than prescriptive. It provides a flexible and broad framework without addressing a specific application domain or stage. This research will use the IDT as a basis for constituting the theoretical framework of innovation adoption. Within this framework more specific theory will be gradually introduced towards creating a comprehensive technology implementation in construction sector research framework for further introducing BIM implementation for an engineering organization.

4.1.2 Technology adoption in organizations - The TOE Framework

From this general theoretical background of IDT, this chapter will further address theory specific for technology implementation. Therefore we will further focus on theories that directly address technology adoption and focus on the implementation process.

According to Oliveira and Martins, 2011, the most used theory for technology adoption at organizational level is the TOE framework (Tornatzky, et al., 1990). The TOE framework differentiates itself from the other main theories of technology adoption which analyze the process at individual level: the technology adoption model (TAM)(Davis, 1989), the theory of planned behavior (TPB)(Ajzen, 1991), unified theory of acceptance and use of technology (UTAUT)(Venkatesh, et al., 2003).

The TOE framework (developed by Tornatzky, et al., 1990) identifies 3 aspects of an organization’s context that influence the process by which it adopts and implements a technological innovation: technological, organizational and enviromental context. (Tornatzky, et al., 1990) (see Figure 14)

Technological context - describes both the internal and external technologies that are relevant to the organization in terms of characteristics and availability. TOE framework stresses that technology is a “knowledge embedded tool” and “is a mixture of social/behavioral elements and
physical elements”. Technology itself is merely a physical tool that involves the knowledge of humans on its purpose, its operation and its impact. The TOE framework does not discuss specifically the characteristics or features of technology as compared to IDT theory. Organizational context - refers to the characteristics and the resources of the organization, including organization’s size, degree of centralization, degree of formalization, managerial structure, human resources and amount of slack resources, linkage between employees (communication processes). The elements of the organizational context of the TOE are strongly linked to the ones of the characteristics of the organization of the IDT. Environmental context is the new category of factors that the TOE framework provides. It refers to the industry characteristics and the market structure, technology support infrastructure, macroeconomic context and regulatory context. The factors adapted based on the integrated models of Oliveira (2011) and Wejnert (2002), are:

3. Environmental context:
   1. political conditions and norms
   2. industry characteristics and market structure
   3. technology support infrastructure

The TOE framework provides a theoretical basis with consistent empirical support with technology adoption specific factors identified within the 3 contexts. This framework is consistent and strongly relates with the IDT theory which emphasizes specific characteristics as drivers for an organization’s innovativeness. There are several researches that combine the TOE framework with the IDT theory to understand technology adoption (a large presentation of such researches is provided by Oliveira, et al., 2011). This research will also use a combination of the 2 theories to further create the theoretical framework for BIM implementation.

4.1.3 Institutional theory

Institutional theory has been used in addition to the IDT and TOE in recent studies. This theory stresses that institutional environments are decisive in shaping organizational structure and actions (Scott, 2001). It states that organizations don’t take decisions on purely rational goals and efficiency, but also by social and cultural factors and concerns for legitimacy. Organizations in the same field tend to behave more homogenously after some time as competitive and customer pressures motivate them to copy industrial leaders. (Oliveira, et al., 2011)

Therefore institutional theory complements the TOE framework by adding one more environmental factor. This is the external pressure, referring to pressure from the competitors, trading partners and clients. (Iacovou, 1995) Furthermore it also justifies having flexibility in selecting the most important factors affecting a specific technology adoption with the importance of the environment context and domain specificity. External pressure will be used in this paper as the fourth element of the environmental context for the combined IDT – TOE framework.

C. Environmental context:
   4. external pressure
4.1.4 Combined IDT – TOE framework and conclusion on technology adoption theoretical models

It can be concluded that the literature review on technology adoption models at organization level has revealed that most studies rely on the IDT theory and the TOE model. Further, a combination of the 2 theoretical models provides a good approach for properly explaining the adoption process. A combined IDT-TOE model is used as well by a multitude of different research authors to explain technology adoption within organizations. (Oliveira, et al., 2011)

The combined IDT-TOE model consists of the elements of the organization and innovation characteristics of the IDT and the elements of the external context provided by the TOE model, additionally adding external pressure provided by the institutional theory. This research will also use the combined IDT-TOE model, aiming to have a comprehensive model capable of explaining the factors that affect technology innovation within an organization which can be further used to analyze BIM implementation.

The approach of this research is to introduce the theoretical model into an organizational structure diagram that explains the different organizational levels where the factors affecting technology implementation can be integrated. The dimensions of this organizational structure are the environment, the company, the division, the team and the individual. Further these dimensions are linked to the levels of decision making within a company: strategic, tactical and operational. This structure is used in order to be able to explain at what level affect the factors presented in the IDT – TOE model the organization and further at what level of decision making should be searched for measures to counter the identified challenges for BIM adoption. The tactical level is considered to be the focus for this research, but the strategic vision and operational level decisions are also considered in presenting the implementation process.

The combined ICT-TOE model integrated in the organizational structure is presented in Figure 15 and will be further referred to as the ICT-TOE framework. In this framework the environmental context has influence on the entire company, which has no or little influence on the elements of the environment. Therefore this set of factors is placed outside the strategic level of decision making of the company.

Initially, the innovation has the same status, having an external source from which it diffuses. Nevertheless, once the awareness and the knowledge of the innovation become high within the organization, the characteristics of the innovation are placed at the company level, because the strategic level decision making takes into account all the factors and is able to choose either to adopt or not the innovation and in what conditions.

The characteristics of the organization have influence at all decision making levels but the most at the tactical level, where effective decisions can be taken towards implementing the innovation at division dimension. This level is presented highlighted as this is the level of decision making where this research will focus for developing measures for BIM implementation. This because, the strategic level is considered to take decisions either to implement or not and to give the vision for what the innovation should become within the company. While the tactic level is able to effectively develop the set of measures necessary to carry out the implementation process and
to apply them at division level, which is the level at which a project is carried out. The operational level is influenced by all the factors of the model, but relies mostly on the superior levels of decision making to overcome the challenges that it faces in the implementation process at team and individual level.

The combined IDT – TOE framework presenting the factors that affect technology implementation within an organization is presented in Figure 15.

Figure 15 Combined IDT- TOE theoretical framework presenting the factors affecting technology implementation within an organization
4.2 ICT implementation and use within the AEC industry theory

This chapter goes further towards presenting theory specific to the technology class of which BIM is part of, ICT (information and communication technology) and referring explicitly to AEC (architecture, engineering and construction) organizations. In this sense, it goes further with answering the research question presented in the introduction. In this endeavor, we will present different studies on the subject, focusing on the research of Adriaanse (2007), which has studied the key mechanisms that influence the way actors (individuals or teams) use inter-organizational ICT in construction projects as well as directions for solutions to overcome the main barriers for the successful use of ICT. As described in the introduction of chapter 4, this theory will be used to further explain the factors and mechanism that influence ICT technology adoption at individual level and complement the theory on organizational level adoption.

ICT is a term that describes a technological communication, coordination and collaboration system that has impact on socially organized human behavior. For construction projects ICT can refer to document management applications, workflow management applications and product modeling applications (3D, 4D or BIM applications representing graphical and non graphical models of building objects). (Adriaanse, 2007)

4.2.1 The specificities of ICT implementation within the AEC industry

The AEC industry is often described as a laggard in adopting new products and processes. The study of Taylor, et al. (2003) emphasizes that the construction industry is especially a laggard adopter of technology innovations which require a coordinated change of processes for multiple organizations. This delay takes place because of the project-based nature of the organizations within the AEC industry, context where systemic innovations diffuse more slowly.

ICT introduction and implementation within an AEC organization requires a process of knowledge development and learning characterized by ambiguity and indefinite duration that goes beyond the time span of a single project. This is in conflict with the project-based mode of organizing used in the industry that has a prime focus on time and costs of projects, usually reinforced with contractual arrangements including fees for delays and structures of wages. This makes it difficult to find the slack resource necessary for project-based organizations to experiment with new ICT and build up this new knowledge base. In case the adoption takes place at the project level, the organization requires further extra slack resources to perform the transfer of the new ideas from the project level to the permanent organization and to adapt the ICT to the organization and vice versa. (Linderoth, et al., 2008)

Although the organizing by projects is considered to be one of the main sources for the relative low rate of adoption of ICT in AEC organizations, this form of organizing is not probably to be replaced in the near future or even not at all. Therefore the AEC organizations have to find different incentives to motivate them to overcome these adoption challenges. One such incentive for an organization to adopt new ICT is the situation when the adoption creates perceived immediate benefits, which makes the adoption directly feasible. An alternative that is a consequence of the different perception on the benefits for different actors for facilitating the adoption process is that one of the actors, with sufficient power to force other actors, makes the
ICT application in projects an obligatory passage point, giving others no alternative than to also consider ICT adoption as one of their internal goals. A third incentive, when performing projects under own management, can be that organizations decide to use a project in order to experiment with the implementation process and to create insight and knowledge. (Linderoth, et al., 2008)

4.2.2 Adriaanse’s theory on actor’s use of inter-organizational ICT in construction projects

The research of Adriaanse (2007) has created a theoretical model specific to the implementation of ICT in construction projects, relating the model to the already existing more general ones (UTAUT, TPB and TAM – individual level implementation models). This model was set in order to find the key mechanisms that influence the way actors use inter-organizational ICT and solutions for the barriers of successful use of ICT in construction projects.

The theoretical model set up by Adriaanse addresses technological, organizational and individual aspects that result in barriers or drivers to a successful use of ICT. The four main mechanisms that determine the way actors use ICT in construction projects in the theoretical framework proposed by Adriaanse are:

D. *Personal motivation*: the extent to which actors are willing to use inter-organizational ICT themselves. Personal motivation influences both the willingness of the actors to use ICT and their willingness to invest resources to overcome barriers to the intended use of ICT.

E. *External motivation*: the degree to which actors are forced by other actors to use ICT. External motivation influences both the use of ICT and the efforts made to invest resources to overcome the barriers to the intended use of ICT.

F. *Knowledge and skills*: the degree to which actors know how to use ICT. When knowledge and skills are limited, the actors themselves are the ones restricting the use of ICT.

G. *Acting opportunities*: the extent to which actors are able to use ICT in the intended way. When the acting opportunities are limited, ICT is not able to support the actions of the actors involved.

These four categories were expanded into sub-mechanisms that present the influences of the way actors use ICT in construction projects. This theoretical framework shows the barriers and the drivers to the intended ICT use and is tested for ability to explain the use of ICT during construction projects over time. These model containing the mechanisms and sub-mechanisms is presented in Figure 16.

D. *Personal motivation* is influenced by two subcategories:

- **D1. Perceived benefits and disadvantages of ICT use**: the extent to which actors perceive the use of ICT as benefiting and/or disadvantaging them. This refers to both experienced and perceived potential benefits and disadvantages. They are influenced by:
  - potential benefits and disadvantages of ICT
  - understanding of the actor about the ICT
  - actual use of ICT

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1 The factors have letters starting from “d” in order to differentiate them from the ones of the IDT-TOE when referring back to the two frameworks.
This category can be either a driver or a barrier for the use of ICT.

- **D2. Perceived time pressure**: the extent to which actors perceive that they have to act quickly when using, or considering the use of ICT. The perceived time pressure is formed by:
  - time investment required to learn to use ICT
  - perceived risks of using ICT
A high level of perceived time pressure moderates personal motivation while a low level does not result in a high level of personal motivation, therefore this category can be only a barrier in the use of ICT but the mechanisms are highly dynamic and the more insight is gained into the use of ICT the effects decrease.

![Figure 16 Theoretical model of Adriaanse for ICT use in construction projects for actors](image)

**E. External motivation** has two subcomponents:
- **E1. Availability of contractual arrangements about ICT use**: the extent to which actors are forced to use ICT because this is mandated in the contract.
- **E2. Presence of a requesting actor**: the extent to which another actors requests certain action to take place and the extent to which this requests impacts the actor use of ICT. The influence of the requesting actor depends on the interest position and the position of the actor.
External motivation can be only a drive towards using ICT, except the situation in which it explicitly opposes ICT use or mandates a different technology. Exerting external motivation is a good incentive in situations when personal motivation does not drive the use of ICT.

**F. Knowledge and skills** mechanism is influenced by:
- **F1. Clarity of procedural agreements**: the extent to which actors know how to act concerning the ICT application (what information has to be communicated to whom, in what form and at what time). This aspect is influenced in 3 ways:
  - motivation to overcome barrier in agreements
  - level of understanding about ICT
  - presence of external procedural agreements
• **F2. Clarity about the operation of ICT**: the extent to which actors know how to operate the application. These subcategories can be only barriers to the use of ICT in the case when not sufficient clarity is present, thus moderating the use of ICT.

**G. Acting opportunities** has as subcomponents:
- **G1. Alignment between ICT and working practices**: the extent to which ICT fits within the actor’s working practices in the project and their organization.
- **G2. Availability of technical means**: the extent to which technological aspect restrict actors in using ICT in the intended way.

These categories can only be barriers to the use of ICT.

The theory presents personal motivation and external motivation as concurring to form the intention to use ICT and the intention to overcome barriers to the intended use of ICT. The knowledge and skills and acting opportunities are presented as restricting mechanisms to the use of ICT, with the most influential subcategories being clarity of procedural agreements and the alignment between ICT and the working procedures, the other two, having a smaller restricting effect. These are the main components of the model proposed by Adriaanse to interpret the use of ICT in construction projects by actors. As suggestions for further research it mentions the development of interventions at an organizational level and strategies and protocols for implementing ICT suggesting that the study is an important entry point for this. The current research fits within these directions, focusing on engineering organization and on implementation of product modeling ICT (BIM).

**4.2.3 Conclusions on the theory of Adriaanse on actors’ use of ICT in construction projects**

The model proposed by Adriaanse (2007) in order to explain the mechanisms that influence an actor’s use of ICT in construction projects has been presented in the above paragraphs. The model reflects actor’s use of ICT in projects. In the context of this research the model of Adriaanse is consider to effectively explain the factors that affect the implementation process at individual level. Thus, to complement the IDT-TOE framework which refers to organizational adoption of technology, by presenting the mechanisms that influence individual level adoption.

This theory is linked to the use of ICT in projects, which is the last phase of the adoption process and the elements of the model are the conditions for optimal ICT use in construction projects. Not being able to meet the conditions for ICT use within projects leads to challenges to adopt the innovation at individual level and thus implement it within an organization. For example, lack of personal or external motivation to use ICT in projects is a challenge towards adopting it for individuals within an organization. Further, not having the required skills or acting opportunities by failing to achieve sufficient clarity in the procedural agreements or in ICT use or lack of alignment between ICT and current working practices or available technical means are as well factors that affect the level of individual adoption within organizations.
The model was introduced in the organizational structure framework presented in subchapter 4.1.4 (page 34) in order to link the factors influencing ICT adoption at individual level to the organizational context and the corresponding levels of decision making. In this context, the 4 groups of factors affecting ICT adoption where linked to the elements of the organizational structure. The personal motivation influences directly the individual adoption process at operational level, where the changes in the way of working take place. The external motivation is influencing the individual from the higher decision making levels, while the knowledge and skills mostly relate to the clarity of procedures and ability to use ICT which can be influenced by the decisions at the tactical level. Finally, the acting opportunities are mostly referring to the interaction between the organizational level and the innovation. Figure 17 presents the Adriaanse’s theory framework in the organizational context, representing the factors influencing individual ICT adoption within an organization.
D. Personal Motivation (+/-)
- D1. Perceived benefits and disadvantages of ICT use
  - Potential benefits and disadvantages of ICT
  - Understanding of the actor about ICT use
  - Actual use of ICT
- D2. Perceived time pressure
  - Time investment to learn ICT
  - Perceived risks of using ICT

E. External Motivation (+)
- E1. Availability of contractual arrangements about ICT use
- E2. Presence of a requesting actor

F. Knowledge and skills (-)
- F1. Clarity of procedural agreement
  - Motivation to overcome barrier in agreements
  - Level of understanding about ICT
  - Presence of external procedural agreements
- F2. Clarity about operating ICT

G. Acting opportunities (-)
- G1. Alignment between ICT and working practices
- G2. Availability of technical means

Figure 17 Framework for Adriaanse's theory - factors influencing individual ICT adoption within an AEC organization
4.3 Challenges for BIM implementation

Chapter 4 has presented relevant theories of technology adoption at organizational and individual level, for all technologies or specific to ICT adoption. Further, it will present the theoretical barriers/requirements that the center point of this research, BIM is expected to face in the implementation process. They will further be referred to as the theoretical challenges for BIM adoption and are intended to present the counterpoints to the main benefits and drives for the adoption of BIM which are presented in Chapter 3. These challenges come in the form of technical barriers, legal and liability issues, regulations, inappropriate business models, resistance to changes in employment patterns, and the need to educate large numbers of professionals. (Eastman, et al., 2011) A thorough literature review will be carried out in order to identify the main challenges for BIM implementation and they will be summarized in a register. It will further be used to analyze the expected challenges in the engineering organization that represents the case of this research and to represent the basis for which solutions will be formed in the implementation plan framework.

The theoretical challenges for BIM adoption will be structured in four groups according to their nature. These groups are: environmental challenges, organizational challenges, individual adoption challenges and innovation challenges. These are linked also with the 3 levels of decision making in an organization, strategic, tactical and operational. The connection with the environment and the high level organizational challenges relate to the strategic level, the rest of the organizational challenges and high level individual and innovation challenges are related to the tactical level, while the rest of individual and innovation challenges are at operational level. This division is further explained in the conclusions of this subchapter and the corresponding diagram. This approach was chosen in order to provide a structured identification of the challenges and a consistent linkage throughout the chapters.

The identified and structured challenges for BIM adoption will be further linked with the main factors from the theory on technology implementation presented in the first part of Chapter 4. The aim is to provide a system to understand the nature of the challenges as well as directions for solutions for the further implementation framework. Thus the main factors of the IDT-TOE framework of technology adoption at organizational level and of the Adriaanse's theory at individual level will be linked with the challenges.

4.3.1 Environmental challenges

The first of the groups presented is the environmental challenges. They refer to the barriers in the adoption process of BIM that are external to the organization. These challenges can only be influenced, avoided or managed by the organization, but are outside its power to change by itself. The main components of this group refer to the industry characteristics in which the organization conducts its business, the governmental regulations and norms that have influence on the innovation and the market context, especially the clients view on BIM use and its understanding of the involved costs and benefits for his projects. Further we will present all the challenges identified that are connected to the environmental context.
4.3.1.1 Level of clients awareness and requesting of BIM
The level of awareness and use of BIM between the clients of an organization has an important impact on the perceived time pressure and speed with which the organization changes the work practice from traditional paper based drawings to BIM models. But this requires that the clients understand well both the costs and benefits of using BIM and that they are convinced to demand it for their projects. This while accepting the risk of allowing BIM to scramble the risk allocation distribution between project parties and to blur the traditional way of working liabilities for design and for construction means and methods. At this point of industry’s experience and adoption of BIM, this is a challenge. (Eastman, et al., 2011) The main factors of the technology adoption framework that relate to this challenge are: B1 Relative advantage of using BIM, C2 Industry characteristics and market structure and C3 Technology support infrastructure.

4.3.1.2 Level of BIM adoption at industry level
Along with the client’s awareness of BIM and its relative advantages, the client’s perception on the level of BIM maturity of the industry influences his likeliness to ask for BIM in projects. Requiring BIM in a market in which only a few companies are able to use it, results in limiting the pool of potential bidders and potentially as a consequence, increasing the project’s price. Therefore, until there is a high adoption of BIM through the industry, the BIM convinced clients will drive more companies to adopt it while innovative companies which use BIM will have to convince more clients of its benefits. Nevertheless, in time and as market evolves, the adoption ratio is rapidly increasing and this becomes less of a challenge. An enquiry in the adoption ratio within U.S. architects has shown that there was a 16% increase, from 34% to 50% BIM usage between 2007 and 2009. Such examples were provided in chapter 3.5. (Eastman, et al., 2011) The main adoption factors to which this challenge connects are: C4 External pressure, C3 Technology support infrastructure and C2 Industry characteristics and market structure.

4.3.1.3 Information exchange regulations and design standards and norms
Legal and contractual changes are required in order to facilitate BIM use within project teams. Project parties are currently often required to communicate and handover information only through paper drawings and traditional means. Especially in public institutions which are governed by national or regional laws this is a challenge as these regulations can only be changed through a lengthy process. Furthermore, standards and norms are not fully defined and uniformly adopted by project owners thus obstructing BIM use for service suppliers aiming to obtain uniformity and compatibility of work practices and consistent and enhanced interoperability. IFC and national standards are currently being refined as presented in Chapter 3, but until they will reach a sufficient development and adoption this will continue to represent a challenge for large scale BIM adoption. (Underwood, et al., 2010) The main related adoption factors are: C1 Political conditions and norms, C3 Technology support infrastructure and B2 Innovation compatibility.
4.3.2 Organizational challenges

The second group refers to organizational challenges. It consists of the challenges which have effect only on the organization and its interaction with the innovation. Thus this set of challenges affect and can be addressed directly by the organization. There are three sub-groups for organizational challenges, those referring to the feasibility of BIM adoption for the organization, those referring to the redistribution of project risks and contractual changes and those that refer to implementation management.

BIM Feasibility

4.3.2.1 BIM justification for a design organization (benefits surpassing costs)
BIM offers the potential of realizing new benefits, but they are not free of charge, they come with a cost. Developing a BIM model involves more effort than the current way of producing construction documents. Moreover, it involves costs for purchasing new systems, retraining staff and developing new procedures. Therefore in order to be justifiable for a design organization, this increased efforts and costs have to be counterbalanced by the benefits.

The benefits, according to the experience of most design organizations that have gone through the implementation process, are making the significant initial costs associated with transition worthwhile, even if just considering the generation of consistent drawings from the model. Further own benefits come in the form of continuous tracking of costs using estimation tools, improved information management by integration with specifications, performance analysis of issues which traditionally are assessed intuitively, development of proprietary libraries of detailing, configurations, and other information, thus facilitating the transfer between personal knowledge to corporate knowledge. An extensive presentation of the benefits of BIM has been made in Chapter 3.4.

Moreover, the current business structure of a construction project involves a fixed price for the design process, usually computed as percentage of the construction costs. Thus the success of a project is not tangible by the design organization. By using BIM, the designers can influence a smoother execution and fewer problems in a project and an improved realization of the design intent, in this sense realizing profit. Influenced by the awareness of BIM benefits for a project, clients and contractors are presently exploring new business opportunities which for the designers can be translated in offering new services that can be added to the fee structure.

First, there are the services which address the creation of the concept design applying performance based design by using analysis applications and simulation tools. These can refer to energy efficiency, sustainability, cost and value assessment during design and programmatic assessment using simulation of operations. A study that supports the importance of such information was performed for a hospital project in the U.S.A. and revealed that 18 months of functional operations for the case hospital are equal to its construction costs. Therefore, making savings in hospital operations, even at higher construction costs, can result in very high benefits and cost reductions. (www.cfm.va.gov/cost)
Second, there are the services which address integrating design with construction, related to project delivery. They refer to improved collaboration within the project team disciplines, improved design review, reduced errors and contingencies issues and enabling faster construction by offsite construction, reducing work on field and increasing safety, and also allowing for automation in procurement, fabrication and assembling. (Underwood, et al., 2010)

The main mechanisms to which BIM justifications for design organizations relates are B1 Relative advantage of innovation, C4 External pressure and A8 Relative position in inter-organizational network.

4.3.2.2 Assessing BIM benefits financially

One of the benefits for designing with BIM is the increase in design efficiency and productivity. Assessing this increase is not an easy task as well as for other benefits of BIM, because it requires experience with proficient BIM use which most implementing organizations don’t yet posses. Furthermore, each construction project is unique in terms of scale, complexity, risks, etc., factor which makes it difficult to compare the productivity in traditional design projects with BIM projects when aiming to achieve a high accuracy for the design efficiency increase. In this sense most information about the increase in efficiency is based on literature and case studies done by external parties which are approximations of the possible effects of efficiency increase for an organization implementing BIM. The only straightforward productivity assessment that an organization can perform is related to the decrease of design errors. This can be done through numbering the decrease in change orders on a project that are not related to client’s change of mind and external conditions change. (Eastman, et al., 2011) Assessing the benefits of BIM has most correspondence with the mechanism of adoption on innovation’s B5 Familiarity, B3 Complexity and B4 Triability.

4.3.2.3 Extent of implementation costs

This challenge is related to the direct costs of implementing a new technology. These costs are training costs and losses of productivity during training and transition, costs of changing work processes and workflows (system configuration, library and document template setup, adaption of design review and approval procedures). It is considered that the investment required for these endeavors exceeds the additional costs which are required for software and hardware improvements. The large extent of the necessary investments leads to the situation in which many service providers are not willing to make this investment unless there is a significant long term benefit for their organization or if there is no large client who is willing to subsidize the training costs. (Smith, et al., 2009) The main related adoption factors to this challenge are A6 Organizational slack resources, B3 Complexity of innovation and B2 Compatibility of innovation.

Implementation Management

4.3.2.4 Developing an organizational strategy and set of goals

Any operational planning process requires that the organization set a clear set of goals and strategy to obtain them. The development and appliance of an implementation plan is supported by the main strategy of the organization and targets to achieve its goals. Further, the individual level personal objectives are a result of the general mobilization effort that is set up in order to
achieve the organizational goals. In this sense, for the implementation process it is very important to have a strong base on a consensual organizational vision towards its intentions with the new technology, a set of goals for it and a strategy to achieve them. (Smith, et al., 2009) The main implementation factors that correspond to this challenge are Organization’s A2 Centralization, A3 Complexity and A5 Interconnectedness.

4.3.2.5 Gaining top management support for the implementation process
Top management support is one of the critical success factors for implementing a strategic technology initiative. Not being able to attract this support can lead to a poor allocation of organizational resources and missed opportunities by not funding the right projects. Therefore the support of an organization’s top management is one of the key elements of a technology implementation project. The project characteristics on return of investment estimates and high strategic importance, duration and complexity are most important for triggering and maintaining this support. (Mooney, et al., 2008) The implementation factors most related to top management support are A1 Individual (leader) attitude towards change, A2 Centralization of organization and A6 Organizational slack.

4.3.2.6 Changes in business model required to incorporate new technology
BIM is a disruptive technology that helps create a new value network and thus eventually is expected to disrupt the existing one by displacing the earlier technology. In the case of BIM, the changes that it brings to the distribution of effort, risks and roles within the AEC industry projects have been presented throughout chapter 3. For an organization therefore, pouring the new technology into the old business model is expected to never get translated into new projects and higher revenues. Therefore, while keeping aware of the difference between good innovations and good technology which lies in the capacity of generating revenues based on the added value, the business model of the organization has to adjust to incorporate the new innovation and allow for it to achieve its higher potential. The main changes to the business model that BIM will require adjusting are for what value are customers willing to pay relative to what they currently pay for, what is the costs structure for delivering the new value and what role is the organization taking within projects (Bergstrand, 2011 ) Managing this challenges relates to the implementation factors A3 Organization’s Complexity, A7 System’s Openness and A8 Relative position in inter-organizational network.

4.3.2.7 Assigning responsibility for BIM implementation and presence of a BIM champion
Decisions can be taken at the top management level and actions can be coordinated by passing instructions through functioning hierarchies, however, problems that manifest in the implementation process of new technology are likely to encounter problems with dynamics which fall outside the understanding and involvement of the decision making level and outside the limited interest and responsibility for the operational level to tackle. This situation leads to an ongoing negotiation process. Therefore there is a need of assigning responsibility for leading the implementation process which leads to concentration of interest and knowledge as well as centralization for the collective action effort. This concentration of interest and knowledge usually is one person or a restricted group which steer the implementation process. This person acts as a BIM champion in the implementation process. (Jones, 2011) This challenge is related to
the implementation factors A1 Individual attitude towards change, A2 Centralization, A5 Formalization.

4.3.2.8 Developing BIM modeling skills and redefining staff roles
Shifting the work practices from traditional to BIM requires changes in the roles of project team members and also in the skills necessary for modeling. This implies acquiring the needed skills for designers to shift from designing to modeling and working in the new paradigm as well as developing new project roles to efficiently assimilating the new way of working. These new roles and skill are eventually reflected in a change on the organizational culture regarding the methods it uses to create its products. (Underwood, et al., 2010) The main related implementation factors to this challenge are A6 organizational slack, A1 Individual attitude towards change and B2 Innovations complexity.

4.3.2.9 Changes in procedural protocols that allow collaborative BIM processes
Work processes and model management procedures have to be regulated in order to enable multiuser and multidisciplinary access and use of BIM models. These rely on the establishment of protocols to manage the process of model updating and editing as well as establishing the location where the model is stored and accessed. The BIM protocol addresses issues such as what BIM constitutive models are to be created, what information and level of detail should be incorporated or linked to the model and how will the model be produced and delivered. (Eastman, et al., 2011) This protocol is to be created for organizational model creation or for inter-organizational model creation depending on the competence of the designing team. The change in procedural protocols relates to implementation factors A4 Organization’s Formalization, B3 Innovation’s Complexity and B2 Compatibility.

4.3.2.10 Interdisciplinary collaboration necessary for working with BIM
An important challenge in achieving a successful BIM implementation within an organization is to get everyone involved to subscribe to the process. This refers to the aspect that BIM is not a tool, but a way of working together in a collaborative environment. Therefore, disrupting the team’s workflow by not involving in the BIM process caused by an individual versus team approach is a difficult to overcome situation and should be avoided. (Kensek, et al., 2012) The related implementation factors are A5 Organization’s interconnectedness, A4 Formalization and A3 Complexity.

4.3.2.11 Required skills to market the organization’s BIM capacity
Having a good BIM capacity is not meaningful without being able to market and capitalize on it. Failing to do so can have different causes from failing to efficiently define the organization’s BIM vision, goals and capability, marketing through relying on the legacy capabilities instead of using the new ones that BIM makes available, failing to clearly define BIM capabilities to clients and failing to create credibility on your capabilities. Therefore the new software and work processes implementation alone are not enough, introducing the BIM capability into the organization’s capability and portfolio and making it a part of its brand, services and DNA is a prerequisite for success. (Joseph, 2012) This challenge relates most with the implementation factors B5 Innovations Familiarity, B1 Relative advantage and A6 Organizational Slack.
Contractual Changes

4.3.2.12 Required knowledge and experience for changing contractual arrangements to work with BIM

Construction is a collaborative activity and BIM enables tighter collaboration than CAD but, in the same time, it requires an increase in sharing liabilities and rewards in workflow and commercial relationships. At this point traditional contractual arrangements are not able to handle collective responsibility and risk sharing between project parties when working with BIM. The challenge consists in developing the necessary knowledge by providing education, experience and time to those responsible of identifying appropriate contractual arrangements to reflect the change of work practices that BIM implies. The issues which should be addressed for this change were presented at points 4.3.2.13, 4.3.2.14, and 4.3.1.3. (Smith, et al., 2009) The factors of the adoption mechanisms that best relate to this challenge are B4 Triability, C2 Industry characteristics and market structure and B5 Familiarity of innovation.

4.3.2.13 Change in contractual arrangements to reflect redistribution of effort and costs

This change is required because of the uneven repartition of effort increase for designing BIM models and benefits to use them compared to traditional design practices. The client, designer and contractor have all distinct economic interests and current construction business models do not reflect the different split of efforts to create model and benefits to use it between parties. The major payoffs go to the contractors and owners while the main effort increase to create information rich models goes to the designers. The necessary business and contractual arrangements to address the issue of the cost of effort increase allocation between project members has to be worked out. (Eastman, et al., 2011) This challenge relates with the adoption factors A8 Relative position in inter-organizational network, C2 Industry characteristics and market structure and B2 Compatibility of innovation.

4.3.2.14 Legal changes regarding ownership and management of model – design liabilities and risks distribution

Ownership of the model (including designs, analyses and construction databases), as well as the responsibility for producing it and the access of different parties to visualize and use its information are all issues when having to work with BIM. Further related issues are clearly stating the purpose for which the model can be used, what information and at what level of accuracy and detail is incorporated into the model, ownership of copyrights for parts of the model and who controls the process of creating and updating the model. These are all issues that arise from shifting from the traditional work practices to BIM and which change the allocation of liability, risk and rights between project members and thus cannot be addressed through old fashioned contract models. Currently, guidelines for BIM work practices and collaborative contracts are being developed and refined by professional groups in order to cover these issues and address the changes that BIM involves. (Eastman, et al., 2011) The related adoption factors are A7 System’s openness, C2 Industry characteristics and market structure and B2 Compatibility.
4.3.3 Individual challenges

The third groups of theoretical implementation challenges are the ones that individual have to overcome. They are related to the mechanisms described by the theory of Adriaanse which states the importance of personal and external motivation as success factors and drives for individual level of adoption of new ICT technology working methods. The lack of personal motivation has to be supplemented by and organizational external motivation for individual to acquire the required level of knowledge and skills. The further challenges are the identified BIM implementation issues that hinder the process for individual adoption.

4.3.3.1 Overcoming individual comfort with familiar work methods – individual drive towards change

The challenge consists in identifying employees who are open to changing the way they work in order to take initiative to work on the first project with the new technology and influence the rest to act in this direction. Further, the challenge consists in providing incentives for a large scale adoption and for exchange of knowledge. In large organizations with offices in different cities, sharing the knowledge and processes between locations may be difficult and will require a comprehensive strategy to exchange newly acquired knowledge. Finally the individual laggards have to be convinced of the advantages of the new technology in order to be able to fully incorporate the new working practice within the organization. (Partridge, et al., 2007) The related individual level implementation factors of Adriaanse’s framework are D1 Perceived benefits and disadvantages of ICT use, E2 Presence of a requesting actor, G1 Alignment between ICT and working practices and F2 Clarity about operating ICT.

4.3.3.2 Individual perceived time pressure to change

Proving the necessity of change has to be accompanied by a perceived time pressure in order to overcome the tendency of individuals to avoid time consuming changes such as adopting new ways of working. The perceived extent of time investment necessary to learn the new work practice and the perceived risks associated with this process have to be overcome by having assigning clear deadlines and responsibilities as well as support for incorporating the new required skills and availability of technical means. (Partridge, et al., 2007) The related mechanisms of individual implementation are D2 Perceived time pressure, E1 Availability of contractual arrangements, F1 Clarity of procedural agreements and G2 Availability of technical means.

4.3.4 Innovation challenges

Innovation challenges are the last group of theoretically identified barriers for the BIM implementation process to be presented. These challenges are derived from the characteristics of the innovation at this stage of development. They refer to the availability of proper technical means to apply the innovation and the compatibility of the technology with the organizations technical capabilities. Further, the main BIM innovation challenges are presented.
4.3.4.1 Required availability of sufficiently developed specialized software solutions
The BIM solutions mostly focus on the design profession, because of the large numbers of the professionals in this field. But each specialized function involved in a project requires specialized BIM software for its specialized functions. The range is from feasibility evaluation, concept design, contracting to fabrication systems. Developing all this software will take place along with sufficient demand from the market due to the capital investment required to develop such tools. Along with the development of software solutions, each organization using BIM will is required to make internally available BIM software platforms and tools suitable for its needs and compatible with the other project team members’ way of working. (Eastman, et al., 2011) This challenge relates to the implementation factors G2 Availability of technical means and B3 Innovation’s complexity.

4.3.4.2 Customization of parametric classes – developing component libraries
As presented in chapter 3.3.3, parametric design results in a trade between the object class modeling, which sets up the system of rules and behavior, and the designing process, that has to create elements that fit within this system. These sets of rules and behavior for BIM objects are created based on standard construction practices and on construction codes that usually provide a good base for most of the design necessities. But there are also situations in which the basic set of object classes provided by a software does not allow for some more special building specifications or object shapes. In these cases the designer has to find solutions to integrate these capabilities into the software. Based on which platform he uses, the options that he has are to either develop a new object class if the software allows him, or to modify one of the existing classes. Nevertheless, this procedure is not a simple one because in the case in which the software has this capability, it requires a lot of experience with the software and in some cases programming capabilities for the user. The software available now provides a difficult customization of parametric object classes or not at all, fact that makes it difficult for small firms to create their own specific object classes and that requires months for users to gain proficiency. The software companies are trying to increase the level in which users can extend the base object classes and create new ones to find solutions for situations not previously anticipated by the BIM software developers. (Eastman, et al., 2011) The main related implementation factors are B2 Innovation’s Compatibility and B3 Complexity.

4.3.4.3 Compatibility – with current IT infrastructure and other systems of the organization
The level of compatibility between the current IT infrastructure used by the organization and the one require to conduct BIM projects, as well as the level of effort required to achieve a good working compatibility between the new BIM software and the other software systems that the organization has in use have a large influence on the attitude towards BIM implementation. The main challenges consists in adapting the current systems to allow for the BIM cloud sharing and linking requirements as well as the high IT memory requirements for running large and complex models. In most implementation cases has been revealed that the costs of adapting these systems are generally consistently lower than the one required to train staff and reach a good proficiency level of BIM. (Eastman, et al., 2011) This challenge is related to the implementation factors B2 Innovation’s compatibility and G2 Availability of technical means.
4.3.4.4 Scalability of BIM models

A BIM model can become a very detailed representation of the project and it can have thousands or even millions of parametric objects with individual shapes and behaviors. This large scale of the project and the level of detail results in very large data sets that have to be managed by the BIM software. In some cases this process becomes sluggish and places practical limitations on the size of the project model. BIM models can become very large in size and thus the parametrical behavior of objects can result in slow response times for working on the model. This issue is called scalability. The problem is that for most BIM software all operations on object shapes take place in memory, which is not always large enough to handle the amount of data. Some other BIM software use file based systems that allow them to open, update and then close multiple files during an operation and thus use the disk memory. The file based systems are usually slower for small projects but their speed decreases very slowly in accordance to the project size growth (see Figure 18). (Underwood, et al., 2010) The related implementation factors to the scalability of BIM are B2 Innovation’s compatibility, B3 Complexity and G2 Availability of technical means.

![Figure 18 Memory based vs. File based system speed](image)

4.3.4.5 Interoperability

Traditionally in the AEC industry, the exchange of information between the participants of a project is done through paper or digital 2D drawings which is a rather simple method but with drawbacks as presented in chapter 3.1. Exchanging information through building information modeling provides improved sharing capabilities with large benefits but at the same time it is a more complex process.

There are 3 levels of exchanging information within BIM. Between a BIM platform and a BIM tool, between BIM tools and between BIM platforms. A BIM tool is an application which has as main capability performing a specific task with a specific outcome. Examples of BIM tools are tools that perform clash and error detections, structural analysis, quantity take offs, project scheduling, energy analysis or cost estimations. BIM platform is an application which generates data for multiple uses, usually its main function being the design of the model. It provides the primary data model that hosts the information and most platforms have incorporated BIM tools and incorporate interfaces for multiple other tools.
BIM interoperability between the main platform and a tool is the fundamental information exchange type. Usually this exchange is only one way, the tool extract the necessary information from the platform, analyses it and outputs in a report that is then analyzed by the user. There are also some tools that after analyzing the information, output results that may automatically update the main model in the BIM platform.

Interoperability between BIM tools is the most straightforward type of information exchange as it deals only with limited amounts of information which is not governed my parametric rules which can differ. Therefore this information exchange not having to do with parametric governed information, for example from a quantity take off tool to a cost estimation tool, is less complex and does not face interoperability difficulties.

The main interoperability issue appears in the BIM platform to BIM platform information exchange process. This because the way the parametric rules that manage the objects in each platform can differ and thus be incompatible (see Figure 19). This situation leads to either using platforms from the same software companies or with the same parametric rules, or exchanging information not parametrically managed (only geometry). This problem is the main issue for advanced BIM users according to McGraw Hill Surveys (McGraw-Hill, 2009). In the past years there are a lot of efforts from different organizations to solve it. The main solution found in order to allow for behavior information being exchanged between platforms is for a “common language” standard for common object definitions including geometry and also behavior. Until this desideratum is achieved, object exchange between different platforms will continue to be limited or even completely fail. (Eastman, et al., 2011)

Figure 19 BIM Interoperability
IFC (Industry Foundation Classes) and CIS/2 (CimSteel Integration Standard Version 2) are product data models which represent geometry (2D or 3D), object type and proprieties and relations between objects information while not having proprietary rights and being publicly available. They are well developed through industry wide efforts, being continuously developed and are starting to be formally adopted by governments and agencies across the world. Thus it is probable that they will become the standard for building models data exchange and integration in the future. Meanwhile, the lack of effective interoperability continues to be a significant impediment to collaborative design. (Eastman, et al., 2011) Interoperability relates with the implementation factors B2 Innovation’s compatibility, B3 Complexity and C3 technology support infrastructure.

4.3.5 BIM Challenges theoretical framework

This section is dedicated to identifying the main challenges associated with BIM implementation in organizations through literature review. The result is in the form of an extensive set of challenges which are grouped based on the sources that produce them. The four main groups resulted are Environmental, Organizational, Individual and Innovation challenges. This grouping was done in order to provide structure to the challenges identified but also to contribute to linking them to the technology implementation theories presented in subchapters 4.1 and 4.2. The further step performed was to link each challenge with the factors from the implementation theories and thus provide directions for the causes and directions for searching solutions.

The further step in creating the BIM challenges theoretical framework is to cluster the challenges based on the decision making levels at which challenges should be addressed. The environmental challenges, referring to barriers to BIM adoption which manifest at industry level, with a high degree of freedom related to the actions of the organization are placed at the strategic level of decision making. The organizational challenges are referring to the feasibility of BIM, the risks and required contractual changes that result from implementing it and the implementation management process. These challenges are placed in the center of the framework as through their solving the challenges are all other levels are addressed. The organizational challenges are placed at a high degree at the tactical level of decision making but with a degree of influence from the strategic level. The third groups are the individual challenges which refer to the personal barriers towards the adoption of a new technology. The level at which they are placed within the framework is operational level with influence from the higher tactical decision making. The fourth group of challenges are the innovation specific challenges which refer to the characteristics of the new technology. The level of decision making at which they are placed is operational level with influence from the tactical level as the links with the implementation theory are referring to technical factors. Further Figure 20 represents the BIM Challenges Theoretical Framework.
Theoretical Framework for BIM Implementation Challenges

**Environmental**
1. Level of clients awareness and requesting of BIM (B1, C2, C3)
2. Level of BIM adoption at industry level (C4, C3, C2)
3. Information exchange regulations and design standards and norms (C1, C3, B2)

**Organizational**
1. BIM justification for a design organization - benefits surpassing costs (B1, C4, A1)
2. Assessing BIM benefits financially (B3, B4, B5)
3. Extent of implementation costs (B2, B3, A6)
4. Developing an organizational policy and set of goals (A2, A3, A5)
5. Gaining top management support (A1, A2, A6)
6. Changes in business model required to incorporate new technology (A3, A7, A8)
7. Assigning responsibility for BIM implementation and presence of a BIM champion (A1, A2, A5)
8. Developing BIM modeling skills and redefining staff roles (A6, A1, B2)
9. Changes in procedural protocols that allow collaborative BIM processes (A4, B3, B2)
10. Interdisciplinary collaboration increase necessary for working with BIM (A5, A4, A3)
11. Required skills to market the organization’s BIM capacity
12. Required knowledge and experience for changing contractual arrangements to work with BIM (B4, C2, B5)
13. Change in contractual arrangements to reflect redistribution of effort and costs (A8, C2, B2)
14. Legal changes regarding ownership and management of the model - design liabilities and risks distribution within project parties (A7, C2, B2)

**Individual**
1. Overcoming individual comfort with familiar work methods – individual drive towards change (D1, E2, G1, F2)
2. Individual perceived time pressure to change (D2, E1, F1, G2)

**Innovation**
1. Availability of specialized software solutions (G2, B3)
2. Customization of parametric classes (B2, B3)
3. Compatibility (B2, G2)
4. Scalability of BIM models (B2, B3, G2)
5. Interoperability (B2, B3, C3)

**Figure 20** Theoretical Framework for BIM Implementation Challenges
4.4 Conclusions for chapter 4

This chapter addresses the subjects of technology implementation and BIM implementation challenges form a theoretic perspective. It sets out to analyze technology adoption theory at organizational level and to create a wide view on challenges of BIM implementation in organizations. In doing so, the chapter answers research question 1c - *What are the main challenges of technology implementation and what are the challenges and their causes for BIM implementation identified through literature review?*.

The literature review has resulted in the identification of several technology implementation theories. At the organizational level the most relevant general theories where presented. These are Diffusion of innovation theory – IDT and the Technology-Organization-Environment Theory. The two theories have been combined and augmented with institutional theory to form a combined IDT-TOE theoretic approach. The reason of this merge is that TOE and IDT are complementary theories as TOE is based on IDT and supplements it with an important set of factors – environmental context. Further the review presented the theory on ICT implementation, presenting the specificities of ICT implementation and focusing on the theory of Adriaanse which addresses actor’s use of ICT in construction projects. In the context of this research, the main factors of this theory where integrated in the organizational framework and used complementary to the previous theory to explain the adoption process of ICT at individual level.

From this perspective of adoption theory and factors affecting technology implementation, the research goes further with presenting the main challenges for BIM implementation as resulted from a thorough literature review. Challenges were used as a term depicting the main barriers and necessary changes required to undertake in order to implement the new technology. The resulting main challenges were 24 and were grouped, by their nature, into four groups: environmental, organizational, individual and innovation challenges. The environmental challenges were related to the industry level of adopting BIM, the legal framework which enables or hinders the use of BIM and client’s awareness and demand for the new technology. At organizational level, the main challenges referred to the feasibility of implementing BIM and the difficulty to assess it, the changes required to implement a new working practice, and the changes required in the contractual arrangements that regulate the re-distribution of effort and risks that working with BIM implies. At individual level, overcoming the individual comfort and reluctance with change and perceived time pressure to change were the main challenges identified. Further, the innovation specific challenges were the availability of developed software, difficult customization of software, compatibility with current systems, scalability and last, but not least important, interoperability. The challenges were integrated in the organizational framework, connecting them with the decision making levels were they can be addressed. Further they were linked with the previous factors of implementation theory, in order to provide directions for addressing the challenges.

Through these steps, Chapter 4 has created the theoretic base on technology implementation at organizational and individual levels and on BIM specific implementation challenges, linked the information and introduced it into an organizational framework. This wide theoretic view forms the perspective from which the further case study results will be analyzed as well as the base for creating the implementation plan template.
5 BIM AT GRONTMIJ – CASE STUDY

5.1 Introduction

The current research project has set to identify the main challenges for adopting BIM and to create a template for an implementation project plan. In order to do this, both a theoretical and a practical perspectives are created. As the theoretical perspective was set up in the previous chapter, this chapter will venture in presenting a practical case of BIM implementation within an engineering organization.

The case study is carried out within the company Grontmij Nederland, focusing on the Wegen Department (WD) which of the Transport and Mobility Division. The department provides designing and consultancy services to its clients, the main ones being Rijkswaterstaat (the Dutch Ministry of Infrastructure and Environment) and the Provincial Governments. The department is split into 3 teams, namely Infraprojecten (road designing), Kunstwerken (bridge designing) and Omgevingsmanagement (environment management). (see Figure 21 Grontmij’s structure and focus department of the case study).

The aim of this case study is to create a good view on the current situation regarding the designing practices within the focus organization which is the commissioning organization - Wegen Department (part of the Transport and Mobility Division of Grontmij) and also to find out the desired situation regarding its future BIM capabilities. Further to reflect on the expected implementation challenges from the viewpoint of the company’s specialists and to analyze them in the context of the implementation challenges discovered through literature review. When collecting information regarding the expected implementation challenges of BIM, the expertise of specialists from Wegen but also other departments will be used in order to have a wider viewpoint and to use the information available regarding this topic at company level. In short, the research questions are answered at the level of the Wegen Department, and the level of focus is
raised to the entire company only reflecting the experience with BIM initiatives and expected implementation challenges. (see Figure 22)

The research questions that structure the aims presented above and to which this case study will give answers to are:

1.b What is the current practice and what are the intentions with BIM within the commissioning organization?

1.d What is the perception of the commissioning organization specialists related to expected challenges and causes for the implementation?

5.1.1 Research Methodology

The information required for answering these questions was gathered through a set of semi-structured interviews with experts on all levels of decision making (strategic, tactical, operational) from the organization.

Semi structured refers to the fact that the interviews followed a clear framework and a set of fixed questions but also allowed for discussions outside this structure. The fixed question were aimed at providing answers directly to the research questions (presented above) based on the position of the respondent in cause. Along with answering these fixed questions, the interviews encouraged each person to go further with presenting his own views, experiences and individual knowledge on these topics, thus gathering a large amount of unstructured but useful information and also generating a good overview on the positions of individuals towards the implementation process.

The fixed part of the interview consisted in the further main questions (which are mirroring the information required for answering the research questions):

1. Current designing situation:
   What is the current situation regarding designing practices (or if the case, BIM usage) within your team/department/division?

The answers to this question were supported by Figure 24 (which is presented in the next subchapter). It intended to identify the current design practices and capacity within the organization and most advanced towards BIM experiences.
2. Desired BIM situation:
   a. What are the intentions regarding the desired situation of BIM usage within your team/department/division?
   b. Is there a consensual opinion formed around these intentions?
   c. What benefits are expected from implementing and using BIM?

These questions were supported by Figure 24 and by a list of theoretical benefits for using BIM corresponding to the list presented in Chapter 3.4.

3. Expected implementation challenges:
   a. What is your perception related to the expected challenges in the implementation process?
   b. What other challenges would you consider for the BIM implementation process?

These questions were not supported by the implementation challenges resulted from the literature review as the intention is to compare the two practical and theoretical findings. But they included asking the respondents to grade and analyze the challenges identified by the respondents prior to them in order to create an overview on the general position towards the expected implementation challenges and to differentiate between views at different decision making levels.

The list with the persons interviewed from within Grontmij (containing also their function and decision making level) is presented in 0. It corresponds with the one presented in the project plan and missing the persons which were unavailable or no longer considered very important for answering the research questions. In total 13 interviews were carried out with persons chosen based on their interest, decision power and/or knowledge regarding BIM. The functions of the persons range from director to engineers and advisors and they represent all 3 decision making level (strategic, tactical and operational).

As described in the presentation of the interview structure, the interviews followed a framework but allowed for different approaches based on each respondent. Therefore, the focus of the interviews differed for each interview; the strategic level persons were interviewed towards identifying the vision on BIM and the desired short-medium term situation. The tactical level interviews focused on the implementation challenges and requirements for working with the new technology. The operational level interviews focused mostly on current design practices and experience with BIM. Also, because of the reference in answering question 3 to the answers of the previous respondents, the 3 level were also interviewed sequentially, allowing the tactical level to refer to the implementation challenges referred to by the strategic one, and the operational level to the 2 levels previous. Finally, a joint meeting was set up, presenting the interview results to the respondents from tactical and operational level in order to discuss the findings and to validate the process. (see Figure 23)

![Figure 23 Interviews Sequence](image)

Further, the research will present the main findings of the case study, starting with a presentation of the case organization and its current engineering practices and experience with BIM.
5.2 Grontmij and its current experience with BIM

5.2.1 Company

Grontmij is one of the leading European companies in the Construction and Engineering industry, having approximately 7500 employees, with a large expertise in the fields of energy, highway, roads, light rail, sustainable buildings and water. The company has its corporate head office in the Netherlands and is split into national branches, acting mainly in Europe but also beyond. Further, the branches are organized in divisions, departments (with a relatively large decision making capacity) and teams. The structure for Grontmij Nederland is presented in Figure 21 (page 56); its largest divisions being Planning and Design, Transport and Mobility and Water and Energy. The report will further use numbers as references for the different divisions and departments in order to differentiate between them.

The company provides engineering, consultancy and management services in the fields aforementioned and does so according to its core principle “sustainability by design”. This principle is applied through enabling the company’s professionals to support their clients in developing the surrounding built and natural environment through constant improvement of the design practices in order to achieve a high level of project performance.

Building information modeling is a technology which enables large enhancements for the performance of construction projects, increasing efficiency and providing important benefits to all project phases. The interest of Grontmij in this technology comes therefore as a normal consequence reflecting on the company’s principle and ambitions. Further the subchapter presents the current experiences with BIM through Grontmij Nederland.

5.2.2 Experience with BIM

The definition of BIM that is used through this research is presented in paragraph 3.2.2 and states: “Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle: defined as existing from earliest conception to demolition.” (U.S. National BIM Standard - NBIMS)

Therefore referring to the experience with BIM in projects performed within the company is sensitive to what is understood by BIM. According to the definition and corresponding to the BIM maturity graph presented in Figure 24 (described at page 61), in order to address the working practices of a project as BIM, it must simultaneously combine a number of characteristics. These are: to be represented through a managed 3D environment which integrates and combines models from all disciplines of the project through BIM tools and with integration performed based on proprietary interfaces as well as to link to the model the project data. Further, linking the commercial data should and managing it through enterprise resource planning software is an enhancement.
One of the topics next to the main questions of the interviews was the experience level of working with BIM within Grontmij. At the level of the commissioning department, at this moment, this experience is limited to working with 3D BIM capable software (Autodesk’s Civil 3D, Bentley’s MX, etc). Nevertheless, according to the paragraph above, this is just a step in the direction of BIM due to the lack of interdisciplinary integration between the project information within a BIM environment and no project data attached to the models.

At company level, there are some more advanced steps towards BIM within different projects. This experience refers to projects which link different disciplinary information, but no complete BIM project has been carried out yet. A research from another TU Delft master student has looked at identifying and listing the projects that have been carried out by Grontmij and feature some of the BIM characteristics (Vos, 2013).

The mentioned list provides 8 independent examples of such projects carried out at different phases with BIM practices. In performing all of these projects BIM protocols where used to standardize the collaboration processes. In neither of them all characteristics of fully BIM practice were present, therefore a complete BIM project has not been carried out from inception until completion. Nevertheless, the projects used either collaborative BIM software, linkage with project information at different detail levels or supported the project through multiple stages. Therefore, having some of these attributes shows that although fully BIM capacity was not yet reached, there are scattered BIM initiatives and therefore there is an incipient level of BIM experience at company level within Grontmij.

5.3 **Current engineering practices of commissioning organization**

This subchapter focuses on the current situation of the engineering practices within the commissioning organization (Wegen Department).

The engineering practices used are in accordance with the type of projects that this organization is undertaking. Its main object of activity is designing infrastructure projects, which can vary from being very complex and requiring a large level of detailing, to small complexity project and requiring low detailing of the solutions. Therefore the approach used in these projects is not constant and varies in terms of the number of disciplines and specialists involved. In referring to the current engineering practices, this case study takes into account that there are smaller projects in which basic approaches are used, but considers as current practice the capacity used in the large and complex projects performed by the organization.

The interviews presented in section 5.1.1 had as one of the main themes, gathering information regarding the current engineering practices within the commissioning organization thus addressing research question 1b. The BIM Maturity Levels Graph was used to support answering these questions. This graph is part of the BIM Strategy Paper of the Government of UK (BIM Industry Working Group, 2011) and was used because it provides an efficient visualization tool representing the different levels of BIM maturity in engineering practices. (see Figure 24)

The graph contains 4 levels of BIM maturity which are defined as follows. Level 0 represents unmanaged 2D CAD with paper as the most likely data exchange mechanism. Level 1 represents
CAD in 2 or 3D format using standardized collaboration tools and providing common data environment, with possible standard data structures and formats. The commercial data is managed by standalone finance and cost management packages with no integration.

Level 2 refers to managed 3D environment held in separate discipline BIM tools with attached data. Commercial data management is performed through an enterprise resource planning software. Integration is performed based on proprietary interfaces or bespoke middleware proprietary BIM. This approach may utilize 4D program data and 5D cost elements as well as feed operational systems. The red line represents required BIM maturity for tendering large public projects in UK starting from 2016. Level 3 represents fully open data processes and data integration enabled by web services compliant with emerging IFC standards, managed by a collaborative model server. This approach can be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes. (BIM Industry Working Group, 2011)

According to the results of the interviews, the general current practice within the commissioning organization is Level 1 on the BIM Maturity Graph. Further, within the whole company as well, the general engineering practices is Level 1, with a few sporadic initiatives of higher level which were described in the previous subchapter. The commissioning organization uses on its larger project 3D CAD standardized design practices, the software solutions most commonly used being Autodesk Revit for bridge designing and Bentley MX for roads. The disciplines designs are not combined into models in the current practice due to several reasons, the main consisting of the limited interoperability between software solutions from different vendors (see section 4.3.4.5 Interoperability) or the insufficient knowledge on the topic, as well as the limited knowledge and use on alternative design solutions (ex. Autodesk Civil 3D) and of reviewing and integration software (ex. Navisworks).
2D standardized practices are still used in smaller projects where more sophisticated engineering practices are not considered time efficient for the project requirements. Nevertheless, 3D CAD design is a spread capability which can be used in projects at this moment and is considered as the current engineering practice of the organization (see Figure 25).

Organization’s current situation:
- Related to project demands:
  - Full L1 3D capability
  - Lower L1 practices in use

Entire company BIM experience:
- Spread initiatives towards more advanced practices, not fully L2

Figure 25 Current BIM Maturity within commissioning organization

5.4 Desired BIM maturity level

“If you don’t know where you’re going, any road will take you there” (Lewis Carroll)

This subchapter aims to present the desired BIM maturity level for the commissioning organization (WD) as resulted from the interviews carried out and relying mostly on the BIM vision at higher management levels.

The interview questions set 2 (see page 57) was aimed at addressing this topic. Again the BIM Maturity Level Graph was used to support the interviewer to graphically express the intentions for the desired BIM level that should be reached by the organization within a short to medium time range (1-3 years).

5.4.1 BIM vision

Within the commissioning organization, at strategic and tactical level, the vision for BIM consists in a clear idea that it is the direction forward. There is concordance between the views of managers on this respect, although no formal decisions support this independently expressed view. This situation is in accordance to the vision at the entire company level, where BIM is considered important for the future and will become an important focus for further development intentions, but there is not yet a clear plan in this direction (resulting in sporadic and uncoordinated BIM efforts at tactical and operational levels).
The reasons for which BIM is considered the direction forward for the commissioning organization are two. One is the increasing belief that BIM is a profitable and efficient working practice. The other is the threat that not adopting BIM represents in an industry where competitors might get ahead through this new practice, threat that can be turned in an opportunity to get ahead through the implementation process.

The answers converged towards indicating a realized Level 2 Maturity BIM as the target for the commissioning organization in the short to medium time range. (See Figure 26)

![Figure 26 Desired BIM Maturity Level](image)

### 5.4.2 Motivation for implementing BIM

**Benefits**

During the interviews, one of the questions referred to the benefits that the respondent considers important and motivating for implementing BIM. The question was supported by a list of theoretical BIM benefits according to the ones presented in subchapter 3.4. The benefits of BIM use were divided in 4 groups based on the different phases of a construction project when they appear. These were planning, designing, construction and facility management benefits. The aim consisted in identifying the most relevant ones for the commissioning organization. The respondents were asked to answer which are from their perspective the main benefits of adopting BIM.

Most answers indicated design benefits as the main focus for implementing BIM. Among this set the most important elements were increased collaboration within design team and different disciplines, clash detection and extracting automatic cost estimates.

As secondary focus for BIM implementation benefits, two other groups were chosen as equally important. The construction phase benefits, having as most important elements the use of BIM...
for quick reaction to design changes, discovering errors and omissions before construction. As well as the planning phase which refers to benefits as feasibility checking, efficient alternative choosing and increased collaboration with clients, partners and stakeholders. An important aspect is the traditional strength of the organization for finding design solutions through alternatives which fit the interest of the client which can be enhanced by using 3D models at the beginning of the project, thus adding value to the planning phase. Another important benefit that is targeted in the value of the information passed on to the project owner through a centralized information source that can be exploited during the facility management phase.

These answers indicate that the organization is considering implementing BIM first of all from increasing the design process efficiency and thus having direct benefits from the change. The second focus justifications are the benefits for its clients who can be either contractors (construction phase benefits) or project owners – governmental agencies (planning and construction phase benefits). Nevertheless, these benefits are proportional with the involvement of the organization in a project, the more involvement it has, the more feasible it becomes for it to work with BIM.

According to the answers in the interviews, the main benefits for implementing BIM, relevant for the commissioning organization, and the relative levels of expected importance of the benefits (computed as a mean from the answers) are presented below. The scale represents 3 squares for significant benefits, 2 for average benefits and 1 for low relevance benefits.

Primary focus: Design benefits
- ■■■ Increased collaboration within design team and within different disciplines
- ■■■ Clash detection
- ■ Extracting automatic cost estimates, analyzing and planning

Secondary focus: Construction benefits
- ■■■ Quick reaction to design changes
- ■■ Discovering errors and omissions before construction

Secondary focus (at same level as previous): Planning and facility management benefits
- ■■ Centralized consistent information
- ■ Alternative choosing and feasibility checking
- ■■ Increased collaboration with clients and partners

Risks and opportunities

The interviews within the organization revealed that along with the benefits that working with BIM brings for the projects carried out, there is another significant motivation for implementing BIM. The increasing adoption from the industry and increasing demand coming from the market are large incentives for adopting BIM. For infrastructure projects this trend was until now not as fast as for the building industry. Nevertheless, this is expected to change and this is influencing the attitudes towards BIM implementation.
The general feeling is that BIM is not a matter of if, but more a matter of when. Therefore an engineering organization such as the one in case has to adopt BIM because the market uses and demands it in to an increasing amount. In the same time also due to the large risks associated with not implementing this innovation which in long term can prove to decrease the position of the organization compared to the competition. Based on personal evaluation derived from the opinions of the organization members, the external motivation is significantly more important than the internal one. Expressed in ratio, the external motivation (related to the risks and opportunities in the market) represents more than 70% of the total motivation to implement BIM for the commissioning organization while the internal motivation (increased project efficiency) is less than 30%. This situation is related to the insufficient knowledge and experience related to the increase in efficiency that working with BIM will provide and also due to the perceived high complexity, time demand and costs associated with the implementation process. Therefore the external pressure and possible risks associated with not carrying out the implementation of the new technology are tangible and more relevant for the organization.

Concluding, in the case of the commissioning organization, BIM is driven by both internal (increase design efficiency) and external (market) incentives. The external incentives come in the form of indirect project benefits for the other parties involved in the projects of the organization, and also in a very large amount in the form of external motivation associated from the market situation. The risks of not adopting BIM are considered as the most important motivation for implementing the new technology and surpass in relevance the project benefits that results from this process. (Figure 27 is a schematized representation of the organization’s motivation for implementing BIM)
5.5 Expected Challenges for BIM implementation process

From the constituted view on the current design practices and desired BIM situation and associated reasoning, the case study goes further with presenting the results of the interviews regarding the challenges expected in the implementation process from the perspective of the commissioning organization, therefore addressing research question 1d.

During the interviews, when answering the questions regarding this topic, the respondents were not shown the results of the literature review on implementation challenges but rather left to express their own expectations in matter of BIM implementation challenges. Also they were asked to rate their view on the challenges expressed by persons prior to them and the interviews had a top down structure, starting with the management and ending with the operational persons. After all interviews were completed, a joint meeting was conducted in which the conclusions were validated and in which a discussion was made comparing the differences between the challenges found in literature and those from the interviews. The aim was to identify what challenges the organization has missed in expressing but considered important and also what implementation challenges from literature were not applicable in this case.

The main results of this section of the case study are presented further. The results are clustered by the same framework used to present the results of the literature review challenges in order to offer an easy comparison tool. The average grade representing the importance of each challenge as rated by each decision making level is be presented in brackets. The grades range from 0 to 3, 0 representing no challenge and 3 representing an important challenge, difficult to overcome.

1. Lack of common view and plan on BIM at company level.

The challenge consists on forming a common view on BIM within Grontmij. The lack of integration for knowledge on BIM results in reinventing the wheel over and over again within the spread initiatives. The difficult communication within the company doesn’t facilitate the exchange of information and learning from each other.
Relevance for each level: S:3 T:2 O:2
Connects to literature identified challenge O4 - Develop an organizational policy and set of goals.

2. Overcoming the comfort of designer with shifting from 2D to 3D to BIM working practices

The operational level persons are used to working with current methods and they are not willing to change easily to BIM. The process of changing the ways in which they currently conduct their work will require extra effort and motivation from them. There is a need for a behavior change and one towards an increased training.
Relevance to each level: S:3 T:3 O:1
Connects to literature identified challenges Ind1 - Individual comfort with familiar work methods and Ind2 - Perceived time pressure to change.
3. **Need for clients to request BIM in projects and invest in them.**

Due to the fact that shifting to BIM requires a large investment and the benefits come to a large extent at the side of the client, there is a need that the client requests it in products and is willing to pay for having these benefits.

Relevance to each level: S:3 T:3 O:2

Connects to literature identified challenge E1 - Level of clients awareness and requesting of BIM.

4. **Required ability to market BIM capacity to clients**

There is a need for having the ability to market the BIM capacity and to convince clients. This requires persons capable of convincing the client of the benefits brought to him by designing with BIM and convincing him to pay for these benefits.

Relevance to each level: S:3 T:2 O:2

Connects with literature identified challenge O11 - Required skills to market the organization’s BIM capacity.

5. **Knowing in what conditions is doing BIM financial feasibility**

The challenge consists in not having enough information concerning the situations in which it becomes financially feasible to work with BIM on projects. Thus, there is a need to develop knowledge related to what characteristics should a project have in order to be financially efficient to work with BIM.

Relevance to each level: S:3 T:2 O:1

Connects with literature identified challenges O1 - BIM justification for a design organization, benefits surpassing costs, O2 - Assessing BIM benefits financially and O6 – Change business model to incorporate BIM.

6. **Difficult integration of BIM into business model**

The lack of sufficient information concerning the changes to cost and revenues that using BIM will bring make it difficult to adopt the new practices. This leads to difficulties for integrating BIM within business models and thus hesitations for its adoption.

Relevance to each level: S:3 T:2 O:1

Connects with literature identified challenges O6 – Changes in business model required to incorporate new technology.

7. **The implementation requires commitment in the form of an large investment**

The challenge consists in the fact that the investment of the organization is consistent and pays off in a rather long time. The costs are direct and indirect, referring to both the investment necessary but also to the initial losses in productivity due to the learning time required to master the new working practices.

Relevance to each level: S:2 T:3 O:3

Connects with literature identified challenge O3 - Extent of implementation costs.
8. Different software solutions used by team not fully compatible in terms of BIM.

The scale of the organization and diversity of project disciplines makes it difficult to find common technical solutions which are suitable for all. Thus different teams have developed skills in different software which are BIM capable on their own but not compatible in terms of BIM with the software used by another team. This causes a large problem in the loss of project information generated by the use of different types of software.

Relevance to each level: S:1 T:3 O:2
Connects with literature identified challenges I3 - Compatibility of innovation and I5 - Interoperability of innovation.

9. Integrating the workflows from multiple teams and departments.

There is a need for a clear workflow structure between the departments which work together for a project (approval and hand over) – the document authorization system. How should the approval of the information which is about to be introduced in the central model organized. This is difficult because of the lack of knowledge regarding the other disciplines making the integration difficult.

Relevance to each level: S:1 T:2 O:3
Connects with literature identified challenges O9 - Changes in procedural protocols that allow collaborative processes and O10 - Required interdisciplinary collaboration increase.

10. Connect levels in order to gain commitment from the managers on changes

The issue consists in connecting people from different levels and departments and linking them together with the management in order to gain commitment on the changes. This will also reduce the competition between different teams on leading the process.

Relevance to each level: S:1 T:2 O:3
Connects with literature identified challenges O5 - Gaining top management support

11. BIM requires more education and training as well as a change in working culture

There is a need to gain more education on the new software and work methods which requires time and money to be invested. At this moment the level of knowledge on the software, working methods and their potential is insufficient within the organization.

Relevance to each level: S:3 T:2 O:3
Connects with literature identified challenges O8 – Developing BIM modeling skills and redefining staff roles.
The above expected implementation challenges by the interviewed persons from the organization are introduced further in the framework used to present the implementation challenges identified in the literature review. Therefore, the main grouping of challenges (environmental, organizational, individual and innovation specific) will be used to classify the case study challenges.

The classification below is done accordingly to the literature study challenges with which the case study results were associated. The spaces of the literature identified challenges that have no correspondence within the practical revealed challenges have been left deliberately blank in order to easily visualize the differences between the two findings. The framework also presents the relevance for each level of decision making within the organization, as resulted from the interviews. The scale used is presented in the first part of this subchapter while the coloring associated with each decision making level is explained in the note on the figure.

The framework shown in Figure 28 presents the expected challenges of BIM implementation according to the views of the engineering organization as well as the organization level at which the challenges are considered relevant. Further, the framework connects the practical findings of the case study with the findings of the literature review and highlights the differences.
CASE STUDY - EXPECTED CHALLENGES FOR BIM IMPLEMENTATION

Environmental
1. Need for clients to request BIM in projects and invest
2.
3. The implementation requires a significant investment
4. Lack of common view and plan on BIM at company level.
5. Connect levels in order to get commitment from management on changes
6. Difficult integration of BIM into business model
7. BIM requires more education and training as well as a change of working culture
8. Integrating the workflows from multiple teams and disciplines based on collaboration increase
9. Required ability to market BIM capacity to clients

Organizational
1. & 2. Knowing for what projects is doing BIM financially feasible
3. The implementation requires a significant investment
4. Lack of common view and plan on BIM at company level.
5. Connect levels in order to get commitment from management on changes
6. Difficult integration of BIM into business model
7. BIM requires more education and training as well as a change of working culture
8. Integrating the workflows from multiple teams and disciplines based on collaboration increase
9. & 10. Integrating the workflows from multiple teams and disciplines based on collaboration increase
11. Required ability to market BIM capacity to clients

Individual
1. & 2. Overcoming the comfort of designer with shifting from 2D to 3D to BIM working practices
3. Different software solutions used by team not fully compatible and interoperable in terms of BIM
4. Integrating the workflows from multiple teams and disciplines based on collaboration increase
5. Required ability to market BIM capacity to clients

Innovation
1. 2. 3. & 5. Different software solutions used by team not fully compatible and interoperable in terms of BIM
4.

Note:
Colored squares represent challenge relevance according to the results of the organization interviews for:
strategic level
- medium challenge
operational level
- significant challenge
5.6 Conclusions of case study

Chapter 5 represents the practical perspective of the research and is the case study of BIM within Grontmij Nederland, focusing on the Wegen Department. The chapter gives answers to two research questions, namely: 1.b What is the current practice and what are the intentions within BIM within the commissioning organization? and 1.d What is the perception of the commissioning organization specialists related to expected challenges and causes for the implementation process?

The company is one of the large engineering organizations in the Netherlands, performing projects and services for most sectors of the AEC industry. The experience towards performing projects according to BIM practices varies throughout the different divisions and departments due to the variation in project types performed and also due to the culture of relative independence relating to the working practices used by each department. Therefore the initiatives for working with BIM are spread throughout the company without a structured common approach. At company level there are projects which were carried out with different features of BIM, but at this point no project was performed according integrally to BIM practices throughout the project phases in which Grontmij was involved.

Within the commissioning department, the current engineering practices are mostly on Level 1 on the BIM Maturity Levels Scale (BIM Industry Working Group, 2011). This refers to CAD designing in 2D and 3D format using standardized collaboration tools and providing a common data environment with standard data structures and formats, without integrating the disciplines designs into common models.

The vision for BIM both within the company and the commissioning organization is that it represents the direction for going forward. There is consensus that the desired level of BIM within the organization is Level 2 (managed 3D environment held in separate discipline BIM tools with attached data with integration based on proprietary interfaces) (BIM Industry Working Group, 2011) within a short to medium time range. The motivation behind these intentions consist of an internal component and an external one. The internal motivation of implementing BIM refers to the direct designing benefits which lead to an increased efficiency for the engineering processes of the organization, most relevant benefits being the increased collaboration within design teams and different disciplines and the clash detection, cost estimation, analysis and planning tolls. The external component is more important for the organization and represents the indirect project benefits for the construction, planning and facility management phases, thus the benefits which are received by the clients, contractors and other parties involved in a project. This motivation comes in the form of a desire from the company to deliver better services and also a significant risk for the organization; the risk of allowing the competition to get ahead with BIM and thus meeting the clients and partners demands for such projects, while the organization lagging behind in this respect. Based on personal evaluation derived from the opinions of the organization members, the external motivation represents more than 70% of the total motivation to implement BIM while the internal motivation is less than 30%. The interpretation is that the BIM adoption process is market driven, leading to the situation in which the organization doesn’t want to move to much...
ahead compared to the demands of the clients and the higher level of the competition with the level of BIM services that it provides. Rather, the main aim is to transform the risks of lagging behind in the process into opportunities of getting into a good position for attracting and fulfilling the market demands for BIM services.

Another important part of the case study refers to the implementation challenges expected by the members of the organization. The information was gathered through the interview process and later analyzed and validated through a joint meeting within the organization in which the results were compared with the literature derived challenges. The challenges derived from the case studies mostly addressed implementation management issues (linking 6 out of 7 of the literature derived challenges) and BIM feasibility issues (3/3). The Individual and innovation challenges were considered significant but not consistently by all levels of decision making. The environmental challenges were considered important but only referred to the need for clients to request BIM. The contractual changes required by BIM practices where not signaled as problems through the interviews. As the two resulting lists of challenges, literature derived and interview derived provided a few significant differences, the joint meeting intended to discuss the relevance of these distinctions and to validate the results. The results were that the literature derived challenges which were not present in the case study results are relevant for the organization and they should be taken into account when creating the implementation plan framework. Furthermore, the most relevant cluster of challenges was considered the implementation management within the organizational challenges.

The results of this case study are supporting Chapter 6 in order to base the practical relevance of the implementation plan framework. The framework is created for a general applicability for engineering organizations that perform this transition and relies on the case study’s results for analyzing and rating the relevance of the actions.
Introduction

Chapter 6 – BIM Implementation Plan Framework develops a structured approach based on technology implementation theory to address the specific BIM implementation challenges identified through literature review and relevant for the case study of the commissioning organization. It addresses the research question 2 What is the proposed set of recommendations for an effective BIM implementation plan template relevant regarding the main challenges identified and the project context?.

The chapter presents the main requirements drawn from the challenges of adopting BIM presented previously and the actions that are considered to effectively address them. For the actions, a combined research method was used, compiling information drawn from literature review and organization interviews with individual recommendations. Further, the chapter combines the actions into a structured BIM implementation plan framework and describes a multi criteria analysis tool to verify the progress of applying the plan. (see Figure 29 Structure of Chapter 6 - BIM Implementation Plan Framework )

Making a deployment plan in good relation to its strategic goals is an essential part in achieving success by a company considering to adopt BIM. The adoption process should not be treated as an ad hoc activity. The novelty and the complexity of the changes are hampering the process and bring many challenges. Therefore, successfully implementing BIM does not resume to upgrading the software and training. Rather, it requires changes in almost every aspect of an organization and not just doing the same things in a different way. It requires understanding of the technology and related processes and an implementation plan prior to the conversion.(Eastman, et al., 2011)

The study of Beaumaster (1999) has made a quantity research among organizations implementing new technologies. Among the conclusions was found that the organizations that had a strategic implementation plan reported a mean rate of implementation effectiveness of 7/7.5 compared to the organizations which didn’t made the implementation based on a strategic plan, which reported a mean level of effectiveness of just 3.75/7.5. We consider this as a good incentive for the next chapter which aims to create a BIM implementation plan framework for engineering organizations.
6.1 Requirements for the BIM implementation process – relevance of challenges

This section gives answer to the research question 2a. *What is an effective set of requirements that reflect the specifications from 1.b and tackle the causes identified throughout phase 1?*

The implementation challenges presented in the previous chapter are considered to be an effective set of requirements for implementing BIM in organizations.

In the previous chapters, the challenges drawn from the literature study are presented without assessing the difference in level of importance between them. The list drawn from the interviews differentiates the levels based on the views of the 3 decision making levels within the organization. In this section these two lists are combined, using the main list of challenges drawn from the literature study and rating their relevance based on the views of the organization.

The scoring system is based on the relevance given to the associated case challenges by the organization members through interviews and the joint meeting. During this meeting, the relevance of the literature challenges was discussed, analyzing and rating the relevance of the initially missing challenges from the case drawn list. The relevance of the challenges was...
discussed in the context of the current and desired BIM maturity levels, and does not imply the relevance for reaching the maturity levels greater than the desired one.

The general relevance score of each challenge is computed on 5 levels, in order to accurately approximate the view of the organization. The previous approach used in Chapter 5 contains 3 levels but for more accuracy the combined relevance score presented here uses 5 levels. The score of each challenge is computed by adding the weighted relevance for each decision making level and tuning the results with the relevance resulted from the joint meeting. The levels of the relevance score represent:

0 – not important challenge, 3 – important challenge,
1 – low importance challenge, 4 – significant importance challenge,
2 – somewhat important challenge, 5 – very important challenge.

The results are presented in the Figure 30 Relevance score of BIM implementation challenges for commissioning organization.

Analyzing the relevance score, at level 5 of relevance, very important challenge is E1 – level of clients awareness and requesting of BIM. Further, E2 – level of BIM adoption at industry level is a medium important challenge. Therefore the environmental challenges for adopting BIM have a high significance for the adoption process although they can only be influenced to a limited extent by the organization. The organizational challenges are numerous and important for the adoption process. The challenges O8 – Developing BIM modeling skills and redefining staff roles is on level 5 of relevance, consisting in a very important challenge for the process. The challenges O3 – extent of the implementation costs and O4 – developing an organizational policy and set of goals are on level 4 of relevance. Furthermore, there are 4 more challenges on level 3 of relevance, 2 on level 2 and 2 on level 1 of relevance. The extent and relevance of the organizational challenges show that they are very important aspects which can be addressed directly by the organization and thus prove the need to have a plan for structuring the adoption process. The other 2 groups of challenges, innovation and individual specific are providing some hindering to the adoption process. The most relevant individual challenge is Ind.1 - individual comfort with familiar work methods and lack of drive towards change (relevance level 4), and the most relevant innovation one Inno.5 – the interoperability of the innovation (relevance level 3). These challenges are in connection with the ones at organizational level and will be addressed through actions at that level.

The relevance of the challenges is used for prioritizing the actions in the following sub-chapter and for assessing the relevance of the actions’ expected outcome and thus the amount of energy that should be invested in that direction.
CASE STUDY – Relevance of Challenges For Organization
- Requirements for BIM implementation process

Organizational
1. BIM justification for a design organization – benefits surpassing costs (B1, C4, A1)
2. Assessing BIM benefits financially (B3, B4, B5)
3. Extent of implementation costs (B2, B3, A6)
4. Developing an organizational policy and set of goals (A2, A3, A5)
5. Gaining top management support (A1, A2, A6)
6. Changes in business model required to incorporate new technology (A3, A7, A8)
7. Assigning responsibility for BIM implementation and presence of a BIM champion (A1, A2, A5)
8. Developing BIM modeling skills and redefining staff roles (A6, A1, B2)
9. Changes in procedural protocols that allow collaborative BIM processes (A4, B3, B2)
10. Interdisciplinary collaboration increase necessary for working with BIM (A5, A4, A3)
11. Required skills to market the organization’s BIM capacity
12. Required knowledge and experience for changing contractual arrangements to work with BIM (B4, C2, B5)
13. Change in contractual arrangements to reflect redistribution of effort and costs (A8, C2, B2)
14. Legal changes regarding ownership and management of the model – design liabilities and risks distribution within project parties (A7, C2, B2)

Individual
1. Overcoming individual comfort with familiar work methods – individual drive towards change (D1, E2, G1, F2)
2. Individual perceived time pressure to change (D2, E1, F1, G2)

Innovation
1. Availability of specialized software solutions (G2, B3)
2. Customization of parametric classes (B2, B3)
3. Compatibility (B2, G2)
4. Scalability of BIM models (B2, B3, G2)
5. Interoperability (B2, B3, C3)

Environmental
E1. Level of clients awareness and requesting of BIM (B1, C2, C3)
E2. Level of BIM adoption at industry level (C4, C3, C2)
E3. Information exchange regulations and design standards and norms (C1, C3, B2)

Note:
The blue color squares represent the relevance score of BIM implementation challenges for the commissioning organization. The scale represents:
☐ - not important challenge;
□ - low importance challenge;
■ - somewhat important challenge;
■■ - important challenge;
■■■ - very important challenge;
6.2 BIM Implementation Actions

This section addresses research questions 2b What relevant recommendations related to the challenges identified can be extracted from literature review on technology implementation, organizational change and BIM implementation? and 2c What set of recommendations could be provided related to possible actions which outcomes’ converge to fulfilling the requirements from point 2.a?.

Therefore it presents recommendations for addressing the BIM implementation challenges presented in this report and groups the recommendations in actions. The actions are addressing either individual or group of challenges, focusing on the most relevant and not considering the challenges with no relevance for the commissioning organization.

The content of the actions is derived from literature review on BIM implementation, case study interview implementation suggestions from organization specialists and personal considerations.

The actions are presented using the model of Simon Sinek (2009), “Why, How, What” which indicates that when addressing an actions, the first type of information that should be explained is why we do that, what is our motivation (see Figure 31). The second information type derives from the question how and explains the methods used in carrying out the actions. Finally the third information is the answer to what, and describes what our goal and final result should be. Sinek (2009) argues that this approach is the natural way of reasoning actions, and that it is one of the reasons why organizations and individuals using it are able to be consistent with achieving success in what they do. As it is considered to be an effective way of describing actions, this approach will be further used in the current chapter.

In the next sections, the actions are presented grouped primary based on the decision making level at which they are carried out. This level implies the level of authority required for carrying out the action and refer to the character of each action (strategic, tactic - organizational, or operational). The actions present why an action should be carried out in connection with addressed challenges, recommendations on how an action should be carried out and what the desired output of the action should be. The report gives recommendations for the actions; detailing them not being part of the scope of this research.
6.3  BIM Initiative Group Actions

The report presents in section 4.1 the distribution of adopters of an innovation correlated with the time of the adoption. It differentiates innovators, early adopters, early and late majority and laggards. Within an organization, the individual adoption of members has a similar structure, and the innovators represent a limited amount of the organization members. These persons have passed stage 1, becoming aware of the innovation and preferably stage 2, gaining knowledge about the innovation characteristics and making a judgment that leads to a favorable or unfavorable view on the innovation.

The case study interviews have highlighted important differences between the attitudes towards BIM within the organization reflecting in spread initiatives of innovators for implementing BIM in projects. The independent approach results in an inefficient approach where the wheel is reinvented all over again and insufficient support is gained at higher levels of the organization. Therefore the first set of actions addresses the need for the innovators within an engineering organization considering BIM adoption to form an initiative group and catalyze the process. This group should be formed at the central level of decision making of an organization (tactical level) in order to have an overview grasp on all aspects of the implementation process and necessary position to combine all levels.

6.3.1 Develop feasibility study for BIM

Why:
The initiative group is formed by persons that are aware of the innovation and have knowledge towards being convinced of its benefits. However, the rest of the organization requires convincing about the advantages of using BIM based on a thorough investigation in order to decide on the opportunity of implementing it.

The addressed challenges are:
• E1: Level of clients awareness and requesting of BIM
• E2: Level of BIM adoption at industry level
• O1: BIM justification for a design organization – benefits surpassing costs
• O3: Extent of implementation costs

How:
A feasibility study aims to objectively and rationally uncover the strengths and weaknesses of the new idea, opportunities and threats present in the environment, assess the costs required to carry through and ultimately the prospects for success. In the simplest terms, the feasibility is judged on two criteria, the costs required and the value to be obtained. (Hoagland, et al., 2000)

For carrying out the feasibility study we suggest a combination of two analysis tools. A thorough analysis of the strengths, weaknesses, opportunities and threats of implementing BIM within the organization and an analysis of the prospects for successful implementation within the organization.
The SWOT analysis should look at the strategic advantages for the organization for implementing BIM, the possible threats of not taking on this mission, present an approximation of the direct effects of the new working method on the company and give an accurate approximation of the costs to make the change.

The company implementation success prospect analysis is required because of the complex change that BIM represents combined with the complexity of a large organization. The ICT-TOE framework presented in section 4.1.2 provides a good tool for carrying out such an analysis.

**What:**
The output of this action should be a thorough and reliable analysis evaluating BIM’s potential for success for the commissioning organization. The evaluation should be done in an objective manner, this being an important factor for credibility as the analysis should be further used to gain internal organization support.

The analysis should contain reliable information regarding:
- Market conditions;
- Current and future value of BIM for organization;
- Implementation cost evaluations;
- Company prospects for successfully implementing BIM.

This report presents information that can be used in the SWOT analysis for implementing BIM by the commissioning organization. It points the benefits of using BIM in section 3.4, the future vision of the technology in section 3.5 and the challenges that can be used to set up the costs and threats for adopting BIM. Nevertheless, in order to create an efficient analysis, information regarding the evaluation of costs of adopting BIM and financial benefit from the increased efficiency of the design process is required. Furthermore, a market analysis of current client’s awareness and requesting of BIM, expected developments and industry level adoption and connection with the marketability of the services of the organization is necessary.

Regarding the analysis of prospects for BIM implementation success for the commissioning organization, this study has gathered information through the case study interviews. The findings towards analyzing the ICT-TOE factors are further analyzed.

**Analysis of factors influencing BIM implementation for the commissioning organization – case study findings**

The information gathered through the interviews with the organization members provided good input towards creating the start of the feasibility study for the organization and thus was included in more detail, compared to the other actions in this chapter.

The main factors affecting technology implementation in the IDT-TOE framework (presented in section 4.1) and those influencing the individual ICT adoption of the Adriaanse’s theory framework (presented in section 4.2) are used to analyze the case of the organization’s prospects for successfully implementing BIM. The analysis compiles the information from the case study
interviews in order to present the current prospects of the commissioning organization towards implementing BIM and giving thus indications for improvements regarding the factors which hinder or stimulate the adoption process. The evaluation of the effects is based on the case study results from interviews and direct observations and each implementation factor is rated for its relative effect on the adoption process on a 3 level scale: strong (+++), significant (++-, --) or moderate (+, -) positive or negative effect. The environmental context factors, the characteristics of the organization factors, the factors of the characteristics of the innovation and the individual adoption of ICT factors are further analyzed for the case of the company.

1. Environmental context factors

**C1: Political conditions and norms**: This factor does not influence the adoption process, as it refers to the legal system and also the political support, which at this point do not hinder nor support the implementation of BIM for the commissioning organization. There is no legal norm stating the need to work with BIM and also no norm that stops or hinders such an initiative. (/)

**C2: Industry characteristics and market structure**: This factor has a mixed influence. The case study organization offers design, engineering and consultancy services for road projects which are usually very large and very complex. Such projects require BIM technology for decreasing project complexity in terms of how the project data is built up, stored and managed. On the other side, the road designing industry deals with large projects involving multiple project parties which have to work in similar or compatible ways therefore making it more difficult to adopt BIM independently. (+/-)

**C3: Technology support infrastructure**: This factor is neutral, there is enough support from the large vendors that provide BIM software to not consists in a barrier towards the adoption process. (/)

**C4. External pressure**: The external pressure factor is a very important aspect influencing the adoption process. This because the decision regarding BIM implementation is considered a large risk or opportunity for the organization, which currently does not manifest significantly due to the position of clients not being very strong towards requesting BIM, but a position which is expected to change in the future and thus prove to be a very important aspect.

Furthermore, the level of knowledge of the commissioning organization regarding the external pressure is insufficient and thus more information is necessary in order to be able to correctly assess the situation. Future developments in the external pressure are expected regarding engineering companies and contractors increasingly adopting BIM due to either efficiency increase benefits or increasing influence from clients becoming more aware of BIM’s potential. Thus there is a need to have a good view on the market situation in order to correctly evaluate the risks and opportunities for an organization that seeks to adopt BIM. At this stage, the external pressure is the largest drive for the commissioning organization. (++)
2. Characteristics of the organization factors

The factors resulting from the characteristics of the organization structure have small to moderate influence for implementing an innovation but with a rather high cumulative significance. The effects are mainly hindering the adoption process for the commissioning organization.

A1 Individual (leader) attitude towards change: Resulting from discussion with organization members, this characteristic of the organization can be described as mildly conservative. Therefore the organization takes mostly calculated risks, this involving also innovation projects. This attitude results in the organization not being among the innovator or early adopter of innovations, but rather with the majority of adopters. (see Figure 13 The diffusion of innovations according to IDT theory). (/)

Internal characteristics of the organizational structure

A2 - Centralization factor: The company’s internal structure centralization is not very high, offering significant independence to subdivisions and allowing for innovation diffusion. This structure also makes company wise decisions more difficult as they require consensus building at management level. (+/-)

A3 – Complexity factor: The scale of the entire company and the extent of disciplines it encompasses results in a high complexity factor for decision making towards implementing new technology. Nevertheless the subdivision relative independence allows for initiative taking thus limiting the hindering effect towards BIM adoption. (-)

A4 – Formalization factor: Formalization is not affecting the process of adoption of BIM. (/)

A5 – Interconnectedness factor: The interconnectedness of each team and department within the company is rather low, negatively influencing the spread of information regarding BIM and the adoption process. This leads to the situation where the same information has to be gathered individually by different departments thus a low efficiency towards implementing the new technology. A better integration of the departments would ease the spread of information throughout the company. (-)

A6: - Organizational slack factor: Currently, the organizational slack of engineering organizations is not at a high level due to the economic situation which influences the AEC industry to a high degree. Within the commissioning organization this reflects in room available for a few concomitant well thought investments in innovation. (--)

External characteristics of the organization

A7: - System’s openness factor: The organization has an open system with significant contact with the exterior therefore allowing for information gathering from exterior sources. This leads to it being aware of the innovation and to a certain degree to the industry’s BIM adoption progress. (+)
A8: - Relative position in inter-organizational network: The position in the market has a small hindering effect on the adoption of BIM for the organization as it has to comply to a high degree with the requirements of clients or contractors with which it does projects and thus not allowing for a high degree of initiative for the engineering organization. A second important aspect would be the amount of involvement within a project that the organization has. In projects where it has a high role and is involved in more phases of the project, the organization can have a higher initiative in using new working methods such as BIM.

Furthermore, the current role of an engineering organization might support changes in the future due to developments towards integrated contracts (e.g. DBFM) for large construction projects. These projects are usually very complex and thus a good match with BIM working methods. The main reasoning is that BIM offers among other benefits centralized information, clash detection, automatic analysis, planning linkage and reuse of information, all important means to manage the complexity of the projects and thus to lower risks and increase efficiency. Nevertheless, this new contract types will translate in a shift of the role of the organization, either by moving more towards a consulting role for clients or towards more designing and engineering role for contractors as clients. This development should be investigated further as it will provide an important factor for engineering organizations implementing new working methods. (+/-)

3. Characteristics of the innovation

B1 – Relative advantage factor: The relative advantage of using BIM for the commissioning organization is considered to be important but in the same time expensive to achieve. Therefore, although the direct benefits of efficiency increase are considered as the second most important drive for the adoption process, they come with perceived costs that make the organization to consider a wider view of benefits when regarding the implementation process of BIM. (++)

B2 – Compatibility factor: The compatibility of BIM with the current systems in use is one of the important factors hindering the adoption or trial of working with BIM. As presented in the challenges section, the lack of compatibility between the software solutions of different vendors in use and also the required upgrades of some of the hardware systems for allowing BIM working, leads to a moderate negative effect on the adoption process. (--) 

B3 – Complexity factor: BIM is a rather complex new technology which produces a significant amount of changes in the ways an organization delivers its products. Furthermore, this adds to the relative complexity of the projects done by the organization, therefore making the shift to be perceived as a rather difficult endeavor. This factor therefore has a negative effect on the implementation of BIM and a stepwise implementation would enable a more smooth transition. (--) 

B4 – Triability factor: The trialability factor of BIM does not have a large effect on the implementation process. (/) 

B5 – Familiarity factor: Familiarity with BIM technology is one of the important innovation characteristics factors that hinders the process of adopting BIM. The limited knowledge within
large parts of the organization regarding what BIM can do and what the implementation process needs to consist of influences the adoption process negatively and requires raising awareness.

(1)

4. Individual ICT adoption factors

D. Personal motivation factors: This factor currently has a negative effect on the implementation within the commissioning organization due to the lack of motivation to commit to an effort requiring change by individuals with unclear personal benefits. But through an effort of gradually raising awareness regarding the benefits that adopting BIM brings to individuals, this factor can have a positive influence on the adoption of BIM. The individual benefits involve shifting towards a role as modelers (engineers) instead of draftsmen which adds significant job security for the future for individuals willing to adapt to the change. The personal motivation factor is very important for implementing BIM into organizations as this process relies heavily on the willingness of individuals within the organization to adopt BIM as their working method. (1)

E. External motivation factors: External motivation is a factor that currently is not influencing the adoption of BIM at individual level but can do so depending on the attitude of leaders towards the implementation process. The factor can positively influence the personal motivation of individual for adopting BIM. Offering hierarchical support of the adoption process for individuals, without adding a large pressure can build up enthusiasm towards the new working method. Further, enthusiasm within the team from colleagues with knowledge on the topic and convinced of the benefits can have a positive effect on individual adoption of BIM. (1)

F. Knowledge and skills factors: The lack of knowledge and skills acts for individuals as the lack of familiarity does for the organization, therefore hindering the adoption process. The knowledge required for adopting BIM for individuals refers to technical knowledge and increased collaboration skills. The difference regarding how this can be tackled consists in the fact that the knowledge can be gained through courses while the skills require practice to gain proficiency. (1)

G. Acting opportunities factor: The acting opportunities factor for individuals is in high relation with the attitude of the organization towards adopting BIM. Therefore until a sufficient degree of acceptance within the organization for implementing BIM in projects is built, there are no large acting opportunities for individuals. (1)
<table>
<thead>
<tr>
<th>Factor</th>
<th>Current effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Environmental Context</strong></td>
<td></td>
</tr>
<tr>
<td>A1. Political conditions and norms</td>
<td>/</td>
</tr>
<tr>
<td>A2. Industry characteristics and market structure</td>
<td>+/-</td>
</tr>
<tr>
<td>A3. Technology support infrastructure</td>
<td>/</td>
</tr>
<tr>
<td>A4. External pressure</td>
<td>++</td>
</tr>
<tr>
<td><strong>B. Characteristics of the organization</strong></td>
<td></td>
</tr>
<tr>
<td>B1. Individual (leader) attitude towards change</td>
<td>/</td>
</tr>
<tr>
<td>B2. Centralization</td>
<td>-</td>
</tr>
<tr>
<td>B3. Complexity</td>
<td>-</td>
</tr>
<tr>
<td>B4. Formalization</td>
<td>/</td>
</tr>
<tr>
<td>B5. Interconnectedness</td>
<td>/</td>
</tr>
<tr>
<td>B6. Organizational slack</td>
<td>--</td>
</tr>
<tr>
<td>B7. System’s openness</td>
<td>+</td>
</tr>
<tr>
<td>B8. Relative position in inter-organizational network</td>
<td>-</td>
</tr>
<tr>
<td><strong>Characteristics of the innovation</strong></td>
<td></td>
</tr>
<tr>
<td>Relative advantage</td>
<td>++</td>
</tr>
<tr>
<td>Compatibility</td>
<td>--</td>
</tr>
<tr>
<td>Complexity</td>
<td>--</td>
</tr>
<tr>
<td>Triability</td>
<td>/</td>
</tr>
<tr>
<td>Familiarity</td>
<td>-</td>
</tr>
<tr>
<td><strong>Individual ICT adoption factors</strong></td>
<td></td>
</tr>
<tr>
<td>Personal motivation</td>
<td>-</td>
</tr>
<tr>
<td>External motivation</td>
<td>/</td>
</tr>
<tr>
<td>Knowledge and skills</td>
<td>-</td>
</tr>
<tr>
<td>Acting opportunities</td>
<td>-</td>
</tr>
<tr>
<td><strong>Scoring system</strong></td>
<td>Positive/Negative</td>
</tr>
<tr>
<td>Strong effect</td>
<td>+++/--</td>
</tr>
<tr>
<td>Significant effect</td>
<td>++/-</td>
</tr>
<tr>
<td>Moderate effect</td>
<td>+/-</td>
</tr>
<tr>
<td>Neutral</td>
<td>/</td>
</tr>
</tbody>
</table>

The IDT-TOE factors influence score for the current organization’s implementation success prospects are presented in Table 4. It can be observed that the factors are currently influencing rather negatively towards the implementation of BIM within the organization. This is an explanation for the rather stagnation of the process and spread initiatives. Nevertheless, this influence can change based on future developments or a feasibility analysis that reveals a strong external pressure effect from the market conditions or a high relative advantage of using BIM. Further, with time the hindering effects of the characteristics of the innovation factors are expected to decrease due to technology developments.

The factors affecting the implementation case within the organization should be further studies in order to support a valuable feasibility study for the company and its decision making process.
6.3.2 *Internal marketing – company level*

**Why:**
Internal support at all levels is required for implementing a new technology and a new way of working within the organization. In order to get this support, the organization members should be aware of the new technology and should become convinced of its prospects. Further, there is a need to identify possible BIM implementation champions for each department and this process is a good method for the BIM initiative group to get in touch with them.

Addressed challenges:
- O5: Gaining top management support
- Ind2: Individual perceived time pressure to change
- O7: Assign responsibility for BIM implementation and presence of BIM champion

**How:**
The feasibility study enables the BIM initiative group to prove the opportunity of using BIM. It can be used as a good support for convincing organization members on the added value of using the new technology through posters, seminars and meetings.

Seminars can be used primary for raising awareness among the organization members of what BIM is and convincing them of the benefits of using it. Thus to create support within the organization for the implementation process and underline the time pressure to change for the organization and individuals. Further, meetings can stimulate the communication process within the organization. Currently as resulted from the interviews, the communication between different departments is not very strong. For the support gathering process, all departments for which BIM is a relevant topic and all decision making levels should be involved in the communication process and this interaction can be stimulated by the BIM initiative group.

The aim of the communication process is to join the spread initiatives on BIM within the organization towards a common action. Further, to create a common view within the company towards how BIM can be used in order to allow a good integration and enable working together for all departments. Throughout this process, within the supporters of implementing BIM should be identified possible BIM champions in order to further support the implementation within each department. The BIM champions should be persons which are supporters of the process, have desire to change and improve the organization and possess experience or capability to work with the new technology.

**What:**
An efficient internal marketing process should:
- Make organization members aware of what BIM is and the opportunity to work according to it and present the time pressure to change;
- Stimulate discussion within the organization in order to reach a common view on the technology and ways to work together with it
- Identify BIM champions throughout different departments
- Gain support of the management towards the implementation process;
6.4 Strategic Level Actions

“If we don’t change direction, then we’re likely to end up where we’re headed.”
(Randy LaNear, An Open Letter to the AEC Industry)

6.4.1 Set up BIM strategy

Why:
It is essential to ensure there is a solid vision where the organization is going to avoid the pitfalls encountered when implementing large scale, radical change such as BIM. Not having this vision at top management level, the effort to adopt the new technology and to integrate it with the organization business practices will struggle and waste dedicated resources. The BIM vision of an organization is also the first aspect that prospective or current clients get in contact with therefore influencing the company’s image.

Although many organization regard BIM as a technology or a technique that should be applied only at the project level, the true benefits of BIM come when positioning within the organization strategic objectives at company level (Smith, et al., 2009). Figure 32 presents an overview on the mechanisms that influence the development of a BIM strategy for an organization.

![Figure 32 Mechanisms for development of a BIM strategy (Kensek, et al., 2012)](image)

The case study has revealed that within the organization there is a lack of or insufficient communication and interaction between departments, which leads to spread initiatives for implementing BIM, mostly on project level. The reason is that the way the company is organized facilitates competition between departments and inhibits exchange of information and learning from each other. Therefore there is a need for a common approach and uniting structure. This approach can avoid each department from reinventing the wheel, thus more cost effectively implementing BIM. Further it can help in reaching interoperable working methods between the departments which is a key element for working with BIM and which is difficult to obtain within a common approach and vision.
Addressed challenges:
- O4: Develop an organizational policy and set of goals
- Inn5: Interoperability

How:
The BIM strategy at company level should be based on a strong reasoning, should develop strategy and principles and set goals for BIM.

The feasibility analysis carried out in the previous phase represents the reasoning for the need of action and the time pressure to do so. While the IDT-TOE framework analysis can be used as a tool to reveal the strong and weak points of the organization in relation with the innovation and give directions for improvement. A thorough feasibility analysis is the prerequisite for setting up a company BIM strategy.

Starting from this perspective the organization should work on forming its vision regarding BIM presenting the desired relation between the company and the technology. The vision should be sufficiently aspirational to unite the various views within the organization. It should be further supported by the steps necessary to achieve.

A BIM strategy should be created for achieving this vision and it should correlate the company’s business strategy with the current and expected development of BIM technology. The strategy should be made in a clear and straightforward manner and it should incorporate how to accomplish together with all the organization this vision and the principles regarding the technology that allow for interoperability of BIM practices for the different departments. Interoperability is an important issue for large organization with a high variety project types resulting in a high number of technical solutions used. Forming a set of principles regarding interoperability at company level is important in order to sustain the same approach when implementing BIM at department level and thus enable working with interoperable solutions between departments.

The IFC open file format interoperability should be considered in this endeavor. Furthermore the strategy should encompass the issue of common BIM object library creation and management. The CB-NL object library (Dutch construction industry initiative on BIM object library) is a good starting point for choosing the approach. The company strategy should support each department to carry the implementation effort further and enable them to have a clear and common structured approach.

Goal setting is an important part of the BIM strategy as it helps the organization to overcome the initial opposition and create short term, medium term and long term goals. This goal setting manner allows for achieving early success which is consider important for maintaining the energy for a long term large scale vision. These goals can be effectively connected with the BIM maturity level graph presented in section 5.3.
What:
• Company vision in relation with BIM
• Company strategy for achieving this vision
• Principles of carrying out this strategy on collaboration and technology interoperability
• Company goals for BIM

Ideally the BIM vision and strategy should be set up by the strategic level of an organization, but it is becoming more common for tactical level management to push through the initiative and gain support from the strategic level, as the suggested approach of this implementation framework.

The BIM strategic report should focus on effectiveness of the implementation process which is translated for the organization into doing the right thing. Therefore the focus of this action should be on developing an approach for the organization to implement the technology that fits its needs and gives most advantages. The focus on efficiency – doing the thing right, should be made at department level in the department implementation plan set up.

There are different guides that can be used as starting points for setting out the organization strategy for BIM such as: US National BIM Standard as UK BSi Standard Framework and Guide to BS1192. Nevertheless, each company has a unique profile and thus a strategy should be set up to conform to its specific needs and business values.

Analyzing the BIM challenges and their relevance, we can state that the BIM adoption process is more a human and organizational issue than a technical one. Therefore in creating the organization’s strategy it is recommended to develop an organization change theory background and to choose among the approach to use: life cycle, evolutionary, dialectical, teleological, social-cognition and cultural (Kezar, 2001).

6.4.2 Establish Strategic BIM Support group and allocate resource support:

Why:
The adoption of BIM is a long time process and prone to face opposition from organization members and suffer from falls in motivation. As the transformation process needs to be propagated, there is a need for strategic level persons within the company to steer the adoption process in the direction set by the strategy plan and look towards reaching the company goals. Further, to allocate resources to support the BIM plan and enable tactical level organization members to put in practice the adoption.

Addressed challenges:
• O7: Assigning responsibility for BIM implementation and presence of BIM champion
• O3: Extent of implementation costs
How:
The establishment of the Strategic BIM support groups should take place after the organization’s consensus on adopting the BIM strategy. A group of strategic level persons within the organization should be mandated to support the adoption of BIM at company level.

The strategic support group’s actions should consist in monitoring and steering the strategy implementation at company level. By doing this, the group should ensure that the company is advancing in the right direction and at the correct pace.

The Strategic BIM support group should be mandated to allocate resources for the implementation process at company level. This refers to creating the common structures for allowing BIM interaction between departments, common model storage, shared object library, etc. Further to enable the BIM initiative group to support the implementation of BIM at each department. The later should be in close connection with the strategic group in order to carry out the required actions of the strategy at tactical level.

What:
- Periodic monitoring of BIM strategy implementation at company level
- Allocate resources to support creation of BIM company structures and libraries
- Enable BIM initiative group to support BIM implementation for each department

6.5 Tactical Level Actions:

“You get what you pay for! With BIM If you think you can’t afford it, then you can’t afford to not do it!” (Randy LaNear, An Open Letter to the AEC Industry)

These actions address each department of the company individually and are carried out by department members with the support of the company’s BIM initiative group and BIM strategic support group.

6.5.1 Find and enable BIM Champions and form Department Implementation Group

Why:
There is a need for a few persons of each department to take lead in the implementation process at tactical level within that department. These persons should be enabled by the department’s management to work with support from the BIM initiative group towards developing and implementing the BIM development plan of the department. Assembling the right team is very important for the further implementation process.

Addressed challenge:
- O7 – Assign responsibility for BIM implementation and presence of a BIM champion

How:
The department management supported by the BIM initiative group should identify the persons who can steer the BIM implementation effort within each department. The BIM internal
marketing process at company level can be a good interaction occasion for identifying potential BIM champions.

The BIM champion position requires a few characteristics. The persons should have a high positive attitude towards BIM as BIM implementation requires dedication and commitment for the process. The attitude of the champions has an essential role within the process and may foster project success.

The department implementation group should consist of one person positioned at the tactical level (or designated by tactical level) – project sponsor and at least one person at the operational level with consistent experience on projects (senior engineer). For the operational level person previous experience with working with BIM software would be valuable as this person should have the potential to develop towards the function of BIM coordination. The persons should be capable of comprehensive personal engagement in the process and to collaborate intensively with the rest of the company’s BIM implementation structure.

The main role of the Department implementation group is to set up with the support of the company BIM initiative group and according to the general strategy, the department implementation plan. Along with developing the plan, the role of the BIM champions should be to involve the organization members in the process and connect all levels of decision making. They should maintain consensus within the department regarding the necessary actions and do internal marketing towards convincing colleagues of the individual benefits of working according to the new methods. In a short description, they should centralize knowledge on BIM implementation and catalyze the adoption process at department level. Possible incentives for success can be tied to achieving development goals.

The implementation groups of each department and the initiative group should be in close connection in a company network in order to share knowledge and experiences.

What:

- Identify and enable at least one person at tactical level and one at operational level for each department to develop the department implementation plan and steer the internal process

6.5.2 Develop business model for BIM

Why:

Although the belief in the economic benefits of BIM, the organizations are confronted with several issues that are not supporting the business strategy to implement BIM. These issues are the lack of immediate benefits of BIM for the stakeholders and the changing of roles and responsibilities within projects. Therefore for most design and engineering organizations, the immediate benefits of BIM are not proportional to the investments in the new technology at the operational level.

Engineering organizations that desire to offer BIM services have to adopt the new technology, install the new software, provide training and become proficient in BIM use, change workflows
and reinvent the design processes. Furthermore, BIM implies a shift of project activities from the later stages to the early design stage and along a change in project payment more towards the early phases of the project and less at the detailing-design, engineering and quantity-specification stages. (Sebastian, 2011)

Furthermore, there are several issues regarding the legal aspects of using BIM in projects regarding the legal aspects of information and communication and the contractual arrangements. As in most countries, including the Netherlands, the current regulations have not been designed to assess the legal status of information supplied in BIM, the structure and format of information and the way of communication when BIM is used. (Chao-Duivis, 2009)

Therefore, an organization implementing BIM should not focus only on the technical and training aspects of the process, but also on analyzing how BIM integrates within its business structure and how it can be fine-tuned in order to be able to compete in the market.

Addressed challenges:
- O6: Changes in business model required to incorporate new technology
- O3: Extent of implementation costs
- O11: Required skills to market the organization’s BIM capacity
- O12: Required knowledge and experience for changing contractual arrangements to work with BIM

How:
Starting from the company’s strategy on BIM, each department should develop its business model to encompass BIM.

The elements of the business model key partners, key activities, key resources, cost structure, value propositions, customer relationships, channels, customer segments and revenue streams (according to Osterwalder, et al., 2010) should be re-evaluated in the context of BIM working methods.

Important elements on the business model changes towards BIM are the choices regarding how to develop the BIM capability of the organization, the development of a marketing policy of the BIM skills of the organization and the approach towards different contract types in relation to using BIM.

There are a few options on how to approach creating your BIM capability, one being doing it independently, with the resources of the organization and its desired conditions, another being focusing on a key client and convincing it to invest in a BIM project and a third to try to approach the entire market for finding BIM projects.

The independent approach is done in the absence of a client driven BIM effort and requires commitment from the management for taking over the costs of the implementation and the risks associated with the learning process during the first project. Nevertheless, after the first project there are no extra costs, and the designing with BIM more efficient. Therefore this approach refers to taking the risks for having long term benefit. The investment necessary is large and pays
off in a rather long time, but the associated risks of not implementing BIM are larger because not having a BIM portfolio of projects can lead to a decreasing of chances to win such projects when BIM becomes a client demand.

The approach of implementing BIM in relation with a client requires finding and convinceing the client of the benefits of BIM and the capability of the organization to offer good BIM services. This approach relies heavily on the organization’s marketing skills which have to be tuned to BIM in order to increase the chances of success. There is a need for the client facing staff to understand BIM services, be capable to engage in high level strategic BIM conversation, recognize the impact of BIM on the industry, be up to date on organizations vision and strategy on BIM and have insights on future technology developments.

Creating a BIM portfolio is further very important for the marketing effort of the organization. For the first projects, it is important for the organization to define how far it wants to go with BIM services and clearly delineating its capability to clients. The approach should be that the company customizes the level of BIM on projects rather than allowing for a vague delineation done by the client in order to successfully manage the BIM expectations. BIM should be presented as a set of processes and technologies that aid the core services offered by the organization, thus providing added value for the client’s projects. Further as the BIM capability increases, the approach can move towards molding the BIM approach on projects based on the client’s views.

BIM use has a high value for the organization when it does a large section of the project in which it is involved, therefore the organization should look towards delivering packages of services and combines services beyond what it has traditionally offered.

The further paragraph presents the main contract types that should be analyzed by an engineering organization towards adjusting its business model when considering to work according with BIM methods on large scale projects. Currently in the Netherlands four contract types are considered in relationship with BIM services: Design Bid Build, Construction manager at risk, Design Build and Integrated Project Delivery (Sebastian, 2011). The DBB contracts present the greatest challenge for using BIM because the contractor does not participate in the design effort and thus must build a new model after design is completed but the issue of collaboration between parties can be addressed through contract requirements. The DB approach provides very good BIM use opportunities due to the single entity responsibility for both designing and constructing. The CMaR approach allows early involvement of the constructor in the design process, thus increasing the value of BIM as a collaboration tool. Finally the IPD contracts are used to maximize the value of BIM on projects in conjunction with lean processes for the project team. There are standard IPD contracts enabling BIM practices published under the series ConsensusDocs by a coalition of over 40 design and construction associations that should be analyzed when considering this option. (Eastman, et al., 2011)

**What:**
- Decide on approach on developing the BIM capability of the department
- Invest in developing BIM marketing skills and knowledge for client facing staff
- Decide on approach on working with BIM in relationship with different contract types
**Department implementation plan set up**

At the level of each department a BIM implementation plan should be set up by the department BIM implementation group with support from the BIM initiative group. This plan should contain the Human resource development plan, Technical resource development plan and the Collaboration Protocol. It should be in resonance with the company’s BIM strategy and the department’s BIM business model.

The implementation plan set up should decide on the pace of the BIM implementation process and the progress verification process towards the plan’s goals. Further, the implementation plan set up should create a mechanism for analyzing, adjusting plan and improving the implementation process while in progress.

**6.5.3 BIM Human resource development plan**

*Why:*
In order to work according to BIM, new roles and functions within the project team are necessary and team members need appropriate training and information in order to be able to contribute and participate in the changing work environment. There is a need to create a human resource development plan in which to establish how the new capability is built up.

Addressed challenges:
• O8: Developing BIM modeling skills and redefining staff roles

*How:*
A BIM approach requires changes in the roles and responsibilities distribution. Traditional roles as draftsmen may disappear. Further, new roles as BIM coordinator and systems integrator appear to support greater coordination for developing and maintaining the BIM model.

There is a need for higher knowledge and capabilities of employees. The designers should move towards the function of modelers involving more engineering work. Further, project leaders should move towards involving more project management tasks. The added value of BIM comes from automatization of some processes regarding project drafting and project data analysis (see section 3.4.3), thus enabling the modelers and project managers to take higher value engineering and project management responsibilities. Thus the projects responsibilities are changed, and a more horizontally management is required, allowing for increased autonomy for modelers. Further, BIM involves an increase in collaboration, communication and exchange of information between project members which are soft skills gained through practice.

The human resource plan should start by analyzing the current personnel of the organization based on current skills and capabilities, potential to develop and motivation. A good model for conducting this analysis is considered the Adriaanse’s theory framework presented in section 4.2.3. In parallel should be analyzed the department’s required roles and knowledge in order to work with BIM and the plan should elaborate on the ways this capacity will be built.
It is recommended to build the human capability on stages, gradually moving towards a general BIM capacity. The proposed stages are presented in Table 5.

**Table 5 Proposed BIM Implementation development stages**

| BIM Project Capable: one group trained capable of fully carrying out a BIM project | BIM Spread Practice: 1/2 of the organization’s human resource is capable of BIM | BIM General Practice: BIM capability is spread throughout the entire human resource |

These stages are used also in building up the technical resources presented in a further section. On the first phase of the plan, the focus should be on getting the basic skills needed for modeling, without very high level of detail for the models. At later phase, the organization can take advantage of the multiple integration and interoperability benefits of BIM.

The trainings should be made in leaps rather than a long and vague process. The required technical knowledge can be built up through BIM courses. The learning process is accompanied by a loss of productivity of employees during the time required to master the new way of working. The study of Autodesk (2012) states that the time required to reach the same level of productivity as with CAD working is approximated at 3-4 months.

Many companies consider the time required to train the employees the new software skills is time unproductive for the company and time which they can’t afford. However, considering that BIM saves a large amount of project time through materials take-offs, clash detection, structural calculations, the benefits alone compensate for the time spent to learn the new technology. The management should support the process and mentor the designers during this process and not assume an immediate increase of efficiency. Without a large pressure, the designers will gain enthusiasm for the new working methods as they will start seeing benefits from the new way of working.

The new roles that BIM working requires are BIM coordinator and systems integrator. The BIM coordinator is the person in the team who will manage most of the BIM related processes: configures and upgrades BIM data sets, ensures that all BIM work is carried out according to BIM standards, maintains data integrity and avoids data corruption, reports on data quality and handles extractions and specifications generation from model.

The systems integrator is an IT specialist that sets up the exchange methods for BIM data generated through the projects and allows for internal and external data flows. This function is also responsible of object library management and can be carried out at company level. The project management role doesn’t change significantly but requires understanding of the processes. Finally the designer role changes into BIM modeler, which is responsible of creating models and processing information. (see Figure 33 Example of BIM project functional organizationFigure 33)
**What:**
- Analyze department’s required functions and knowledge requirements to work according to BIM (preferably divided by levels: BIM capable, spread practice and general practice)
- Analyze current human resource, functions, motivation and capability/potential (recommended to use individual adoption framework presented in this report)
- Develop training plan in accordance to general department implementation plan, including: knowledge of management of BIM project, BIM integration and coordination and modeling skills.

6.5.4 *Technical resource plan*

**Why:**
There is a need to develop the technical resources in order to work according to BIM. The requirements are BIM software and tools, adequate hardware resource, creation of project data database and object library. A technical development plan should be set up within the department BIM implementation plan and should be made in accordance to the principles of collaboration and interoperability set up in the company BIM strategy.

Addressed challenges:
- Inn2: Customization of parametric classes
- Inn3: Compatibility
- Inn4: Scalability of BIM models
- Inn5: Interoperability

**How:**
The plan should be created by the Department BIM implementation group with the support of the BIM initiative group and support from IT specialists. The plan should be integrated within the department BIM implementation plan and correlated with the human resource development stages presented in Table 5.
The starting point for this endeavor would be to analyze the current organization’s technical resources. From this perspective to analyze the technical requirements for achieving the BIM department implementation plan.

The first choice is what software solution to use. It is essential to allow for interoperability between the software solutions used by different disciplines within the organization and to consider requirements for interoperability with external partners. Further to allow for compatibility with current systems in use. It is also very important to consider the requirements of the downstream processes.

The survey of Khemlani (2007) analyzed the most important requirements for BIM solutions in a survey addressed to AEC professionals. The results on the top 10 requirements are presented in Table 6.

Table 6 Top requirements for BIM solutions (Khemlani, 2007)

| 1. Full support for producing construction documents so that another drafting application need not be used | 2. Smart objects, which maintain associativity, connectivity, and relationships with other objects. |
| 3. Availability of object libraries | 4. Ability to support distributed work processes, with multiple team members working on the same project |
| 5. Quality of help and supporting documentation, tutorials, and other learning resources | 6. Ability to work on large projects |
| 7. Multi-disciplinary capability that serves architecture, structural engineering, and MEP | 8. Ability to support preliminary conceptual design modeling |
| 9. Direct integration with energy analysis, structural analysis and project management applications | 10. Industry foundation classes (IFC) compatibility |

Therefore evaluation criteria for selecting BIM software should consider openness, full interoperability of open standards and formats which are mandatory for a large scale use. The Industry Foundation Class (IFC) is a largely used open standard allowing for interoperability. Current open object library and object definitions should be investigated. In the Netherlands, the CB-NL industry wide initiative should be considered.

Further, selection should consider mature and future compliant solutions that fit well with the processes of the organization and its IT environment and possible with the external partners. Solutions which require investing significantly in customization should be avoided due to the high effort required by the process.

It is advisable to have a strategic partnership with ICT vendors on implementing the technical requirements. Furthermore, to take part in BIM industry initiatives and associations in order to have a good view on the technology developments.

Interoperability is a nagging issue that various types of models are going through. A simulation of the BIM process is advisable to test all the compatibilities and results and the skills of the team members. This can consist on taking a small portion of a current project (or sample project).
and testing all the anticipated potential problem areas. This will help reveal many of the possible issues and help improve the processes.

Compatibility with the current software environment of the organization is a very important issue as all project information should be linked or integrated with the model. The GIS software, project information management tools and other software that contain project information should be compatible with the BIM solution chosen. Further COBie (construction operation building information exchange) is a strong non geometric project model data management solution that should be considered. It helps record important project data at the point of origin including equipment lists, product data sheets, warranties, spare parts lists ant preventive maintenance schedules. This information is essential for supporting operations and maintenance and asset management for in use constructions.

**What:**
- Analyze current software and hardware resources compliance with BIM requirements
- Identify and plan acquisition of software solutions that allow for a high interoperability and compatibility with current company software and designers skills
- Enable an exchange system for linking of BIM project data and an object library

In the case of the commissioning organization, the current situation of working practices and desired level of BIM maturity have been presented in Chapter 5 and Level 2 on BIM maturity was selected as short-medium time range goal. This level requires interoperability within the BIM software solutions used which currently does not exist due to the use of proprietary formats and the lack of linking of project information. A first phase technical solution for this issue should consider the IFC open standards and the integration of models using BIM project review software.

### 6.5.5 Internal marketing – Department level

**Why:**
The reasoning for an internal marketing where presented in section 6.3.2 Internal marketing – company level. This section reflects on the department level marketing action which addresses especially the operational level organization members. There is a need to develop trust and understanding of BIM in order to motivate individuals to change. Motivated and enthusiastic individuals towards BIM are the key to implementing BIM within organizations.

Addressed challenges:
- Ind1: Overcoming individual comfort with familiar work methods – individual drive towards change
- Ind2: Individual perceived time pressure to change

**How:**
The internal marketing at department plan should focus on dealing with overcoming the individual comfort with familiar work methods and stimulate the individuals within each department to accept, become involved and support the change.
The action should be continuous throughout the development of the implementation process with more energy involved in the first phases when the level of opposing to the change is higher. The process should address all functions of the department that have to change the way that are currently working, focusing on the designers and the project leaders. Project leaders can prove to be resistant to the change as they are the one carrying the financial and time pressure of the projects. Further, the change of working methods is especially difficult for older generations for which developing skills to work with the new technology doesn’t bring a long term career value.

Learning to work with BIM offers a good career boost and safety for the long term and presenting this to the organization members can help counteract the lack of individual motivation and create a perceived time pressure to change. An open conversation approach in which the persons are encouraged to reflect on the skills and knowledge future required for them in the context of the developments in their field is advisable.

**What**
- Convince organization members of the benefits of developing BIM skills and the time pressure to change

6.5.6 **Develop collaboration and procedural protocol**

*Why:*
BIM is a way of working together in an integrated way. Working according to BIM on projects requires a significant increase of collaboration between the project parties but also creates an integrated workflow. There is a need for a structure for regulating the different approach, and this represent adjusting the internal procedural protocols for BIM.

**Addressed challenges:**
- O9: Changes in procedural protocols that allow collaborative BIM processes
- O10: Interdisciplinary collaboration increase necessary for working with BIM

*How:*
Starting from the goals and requirements of BIM, specifications can be drawn for structuring the collaborative and integrated process.

The main aspects to be tackled within the project procedural protocol are: planning how the elements of the project are built up and who coordinates the entire project. How is the update process of the model carried out and the communication of project data internally and with external entities. How is the project revised and feedback loop for improvement. The protocol should provide that the parties sharing the model are not responsible for changes or additions made by downstream users, determine who is responsible for errors in the model at each phase of the project and who has version control and provides changes to the model.

There are several guides and standards for procedural protocols for an organization intending to implement BIM in projects which should be considered: the Standard protocol for use in projects using BIM (Beale and Company, CIC/ BIM Pro, 2013), the Autodesk Deployment Plan
(Autodesk, 2010) and the Project execution planning guide developed by the Pennsylvania State University (CIC, 2010).

**What:**
- Provide a structured plan for BIM use in projects describing responsibilities, deliverables, level of detail and model management.

The operational level actions refer to putting in practice the Department Implementation Plan which is developed at tactical level. Therefore the actions at operational level consist in carrying out the BIM human resource development plan (presented in section 6.5.3) and the Technical Resource Plan (presented in section 6.5.4).

6.6 **Structure for BIM Implementation Plan Framework**

The BIM implementation plan framework proposed by the current report is formed by combining the BIM implementation actions based on their interdependencies into a phasing framework towards planning a structured BIM implementation process relevant for the case study organization.

The framework can be considered for structuring the BIM implementation process within other engineering organizations, but the compatibility should be analyzed and the framework adjusted according to its applicability as the presented version has been tuned based on the results of one company case study.

6.6.1 **Implementation Plan Phasing**

The approach used in creating the BIM implementation plan framework is to integrate the actions addressing the BIM challenges with the stages of technology adoption. The framework is presented at the end of this section in Figure 35.

The proposed framework stages, based on the IDT theory (see section 4.1.1), adapted for the process of BIM implementation within an engineering organization are:

1. Raising awareness
2. Reasoning
3. Decision making (used for strategic decisions made at company level)
4. Planning implementation (this stage is added as a division of the decision making stage, addressing in the context of this research the implementation decisions at department level)
5. Implementing (this stage is divided into 2 phases for gradual development of BIM capacity)
6. Confirmation
Stage 1 commences with the establishment of the BIM initiative group. The group further takes action by developing a feasibility study for BIM and starting the BIM internal marketing process at company level focusing on raising awareness of the new technology.

Stage 2 represents reasoning the need for action. Based on the feasibility study carried out in previous phase, the initiative group reasons to the organization the opportunity of implementing BIM and the time pressure to do so and focuses on gaining top management support. During the internal marketing process, the group should identify possible BIM champions to further support the process at department level.

Stage 3 is decision making. With sufficient support at company level built up, the group initiates a set of meetings at the strategic level to discuss strategic issues of BIM and its implementation and stimulate consensus within the top management on key issues on BIM in order to develop company strategy. Further, the internal marketing process at company level continues throughout this phase.

Stage 4 in implementation planning which represent the decision making process for each department. First the BIM champions within each department are identified and organized into an implementation group. Further the department level management works towards creating a business model that supports integrating BIM and is in tune with the company strategy. Based on the business model and the company strategy, the BIM champions work towards a department implementation plan with support from the company initiative group and get the plan approved. The plan consists of the goals for the process, a human resource development plan and a technical resource plan. Concomitantly, internal marketing actions are carried out at department level by the BIM champions. At company level there is set up a strategic BIM support group that enables the company initiative group, allocates support resources and monitors process. The BIM initiative group actions are to support each department with carrying out the actions and steering the process in the directions set by the company strategy.

Stage 5 represents implementation of the plan developed in the previous stage. The department tactical level carries out the changes to enable the implementation of the business model for BIM. At operational level the Department Implementation plan is carried out; the development of a suitable human resource (action 4.1 in Figure 35) and the development of BIM suitable technical resource (action 4.2 in Figure 35). The stage is divided into 2 phases to allow for a gradual buildup of BIM capacity (phase 1: BIM project capable, phase 2: BIM spread practice). After each phase, evaluation of plan results and improvement of processes take place. For smoothening transition to collaborative BIM working on project, standard BIM collaboration procedural protocol is developed by the BIM champions. The internal marketing at department level continues creating a positive attitude towards BIM implementation at individual level.

Stage 6 is confirmation which represents a reflection on results for the implementation process both at company level and at department level, re-evaluating decisions made at stage 3 and 4 and improving processes for going further towards creating a BIM general practice capacity.
The framework contains a set of milestones. The first one is the case in which the feasibility study indicates a lack of prospect of the new technology for the organization disregarding what actions are taken regarding the process; situation in which further actions should not be carried by the initiative group. Second, failing to reach company consensus on support for BIM during stage 3 can lead to the analysis of possibilities such as limiting the implementation at division or department level. Advancement to the actions of the next stage should be considered after attaining a 2/3 completion of the desired outcomes for the actions of the current stage. Carrying out action for completing one stage can be done simultaneously with incipient actions of next phase. Analyzing the progress of each action should be done according to a success verification tool (the proposed approach is presented in Annex D - Implementation success verification tool).

The BIM implementation plan framework is presented in Figure 35. The Complementary Annex representing the details of each action in the framework in terms of addressed challenge, desired outcome and prerequisite actions is shown in Table 7.
2.1 Set up BIM Strategy:
- Company vision and strategy
- Principles on technology
- Company BIM Goals (O4, Inn5)

2.2 Establish Strategic BIM Support Group and allocate resource support:
- Enable initiative group, allocate resources, monitor company implementation (O7, O3)

1.1 Feasibility study for BIM - Analysis of:
- Market Conditions
- Value of BIM
- Implementation costs
- Company prospects (E1, E2, O1, O3)

1.2 Internal Marketing - Company Level (O5, Ind2, O7)

1.3 Support BIM strategy implementation at department level
- 3.1 Find and enable BIM Champions and form Department Implementation Group (O7)
- 3.2 Develop business model for BIM (O6, O3, O11, O12)
- 3.3 Department Implementation Plan Set up:
  - 3.3.1 Human resource development plan (O8)
  - 3.3.2 Technical resource plan (Inn2, Inn3, Inn4, Inn5)
- 3.4 Internal Marketing - Department Level (Ind1, Ind2)

3.5 Collaboration and Procedural Protocol (O9, O10)

4.1 Human resource development
4.2 Technical resource development

<table>
<thead>
<tr>
<th>Phase</th>
<th>Raising Awareness</th>
<th>Reasoning</th>
<th>Decision Making</th>
<th>Planning Implementation</th>
<th>Implementing - Ph 1</th>
<th>Implementing - Ph 2</th>
<th>Confirmation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsible</td>
<td>BIM Initiative Group</td>
<td>B.I.G. and BIM Champions of each department</td>
<td>B.I.G. and BIM Champions of each department</td>
<td>B.I.G. and BIM Champions of each department</td>
<td>B.I.G. and BIM Champions of each department</td>
<td>B.I.G. and BIM Champions of each department</td>
<td>B.I.G. and BIM Champions of each department</td>
</tr>
<tr>
<td>Scale</td>
<td>Company Level</td>
<td>Department Level</td>
<td>Company Level</td>
<td>Department Level</td>
<td>Company Level</td>
<td>Department Level</td>
<td>Company Level</td>
</tr>
<tr>
<td>BIM Capacity</td>
<td>Analysis</td>
<td>Support</td>
<td>Strategy</td>
<td>Plan</td>
<td>Project capable</td>
<td>Spread practice</td>
<td>General practice</td>
</tr>
<tr>
<td>Timeframe</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Figure 34 BIM Implementation Plan Framework

BIM IMPLEMENTATION PLAN FRAMEWORK

Strategic

Tactical

Operational
<table>
<thead>
<tr>
<th>Action</th>
<th>Why - Addressed Challenges</th>
<th>What - Desired Outcome</th>
<th>Prerequisite actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Feasibility Study for BIM</td>
<td>E1, E2, O1, O3</td>
<td>Reliable information regarding market conditions, value of BIM, future prospects and implementation cost evaluations</td>
<td></td>
</tr>
<tr>
<td>1.2 Internal Marketing - Company Level</td>
<td>O5, Ind2, O7</td>
<td>Raise awareness on BIM and present time pressure to change; reach a common view on the technology; identify BIM champions; gain support of top management.</td>
<td>1.1</td>
</tr>
<tr>
<td>1.3 Support BIM strategy implementation at department level</td>
<td></td>
<td>Counsel the Department implementation groups towards developing required actions</td>
<td>2.1, 2.2</td>
</tr>
<tr>
<td>2.1 Set up BIM Strategy</td>
<td>O4, Inn5</td>
<td>Company vision and strategy, principles on technology, company BIM Goals</td>
<td>1.1, 1.2</td>
</tr>
<tr>
<td>2.2 Establish Strategic BIM Support Group and allocate resource support</td>
<td>O7, O3</td>
<td>Monitoring implementation at company level, allocate support resources, enable BIM initiative group</td>
<td>2.1</td>
</tr>
<tr>
<td>3.1 Find and enable BIM champions and form Department Implementation Group</td>
<td>O7</td>
<td>Identify and enable at least one person at tactical level and one at operational level for each department to develop the department implementation plan and steer the internal process</td>
<td>1.2, 2.1</td>
</tr>
<tr>
<td>3.2 Develop business model for BIM</td>
<td>O6, O3, O11, O12</td>
<td>Decide on approach to develop the BIM capability of the department, develop BIM marketing skills and analyze BIM contracts</td>
<td>1.1, 2.1</td>
</tr>
<tr>
<td>3.3 Develop Implementation Plan set up</td>
<td></td>
<td>Decide on pace and goals for the implementation process and verification process</td>
<td>1.3, 2.1, 3.1, 3.2</td>
</tr>
<tr>
<td>3.3.1 Human resource development plan</td>
<td>O8</td>
<td>Analyze current and required department human resource and functions and develop training plan</td>
<td>1.3, 2.1, 3.1, 3.3</td>
</tr>
<tr>
<td>3.3.2 Technical resource plan</td>
<td>Inn2, 3, 4, 5</td>
<td>Decide on BIM software solution, analyze requirements for achieving it and plan technical resource development accordingly; enable data exchange system and object library</td>
<td>1.3, 2.1, 3.1, 3.3</td>
</tr>
<tr>
<td>3.4 Internal Marketing - Department Level</td>
<td>Ind1, Ind2</td>
<td>Convince organization members of the benefits of developing BIM skills and the time pressure to change</td>
<td>1.1, 3.1, 3.3.1</td>
</tr>
<tr>
<td>3.5 Collaboration and Procedural Protocol</td>
<td>O9, O10</td>
<td>Provide a structured plan for BIM use in projects describing responsibilities, deliverables, level of detail and model management</td>
<td>3.3</td>
</tr>
<tr>
<td>4.1 Human resource development</td>
<td>O8</td>
<td>Develop human resource according to implementation plan</td>
<td>3.3.1, 3.2, 3.4</td>
</tr>
<tr>
<td>4.2 Technical resource development</td>
<td>Inn2, 3, 4, 5</td>
<td>Develop technical resource according to implementation plan</td>
<td>3.3.2, 3.2</td>
</tr>
</tbody>
</table>
6.7 Conclusions Chapter 6

Chapter 6 centralizes the previous findings of the current research towards providing answer to research question 2. *What is the proposed set of recommendations for an effective BIM implementation plan template relevant regarding the main challenges identified and the project context?*

A set of recommended actions for the implementation of BIM within an engineering organization is developed throughout the chapter. The actions are described in terms of: why – relation with addressed implementation challenges, how – recommendations for carrying out the actions and what – desired outcomes of the action. The requirements of the process are the BIM implementation challenges derived from literature review based on the relevance for the commissioning organization.

BIM implementation requires involvement from all organization decision making levels. The BIM implementation framework links the actions with these levels and with technology adoption phasing and describes the connection between the actions. The phasing of the framework contains 6 stages: raising awareness, reasoning, decision making, planning implementation, implementing and confirmation.

The proposed implementation plan framework is based on initiative for BIM implementation at tactical level from organization members which possess innovative drive towards BIM. The most relevant actions are creating a BIM initiative group and developing a BIM feasibility study for reasoning the need for BIM to the rest of the company. On strategic level, it is important to develop a strategy for the technology for the entire company and to monitor and support its development. At tactical level, within each department, the implementation’s process most relevant actions are to develop a business model for BIM and an implementation plan for human and technical resource development as well as to convince the operational level personnel of the individual need to change towards BIM working methods. The operational level’s most important actions are to apply the implementation plan and acquire adequate skills and technical resources for working according to BIM methods.

The proposed structured approach to BIM implementation presented throughout Chapter 6 is considered relevant for organizing the process within the commissioning organization. Starting with an implementation plan framework is a very important step for increasing the chances of success for organizations intending to adopt BIM. The proposed framework can be considered for adoption cases of engineering organizations but its validity should be analyzed for each implementation case.
The main research question of this research is: *What are the causes for the main challenges that influence BIM implementation within an engineering organization and what is the proposed set of recommendations for an effective BIM implementation plan template relevant to the commissioning organization?*

The answer to the question can be divided into two parts. The first part provides explanatory knowledge, presenting the main challenges and their causes for BIM implementation within engineering organization and is addressed in this chapter in section 7.1 Main conclusions. The second part of the question provides prescriptive knowledge, giving recommendations for how the situation can be changed and is addressed in this chapter in section 7.2 Main recommendations. Section 7.3 Discussion represents a reflection on the research carried out by the author.

### 7.1 Main conclusions

Building information modeling (BIM) reflects the aspiration of the AEC industry (architecture, engineering and construction) to increase efficiency within its projects through optimizing the processes of development, management and analysis of project information.

BIM technology enables the creation of a virtual model of the building’s spatial, physical, quantitative and qualitative characteristics. The main features of the new technology that differentiate it from traditional construction design practices are digital representation of components through parametric ruled objects, including component’s behavior describing data, and consistency and non-redundancy of project information.

These features allow for the technology to provide functions and capabilities that lead to a series of benefits for engineering organization working according to BIM. The main benefits being:

- centralized, consistent and non-redundant lifecycle project information
- automatization of project analysis through software tools for: clash detection, cost estimation, time planning, energy use, allowing for project efficiency gains, decrease of inconsistencies and mitigation of project risks

The case study carried out at Gronstmlj Nederland, focusing on the Wegen (Roads) department has indicated that there are forming initiatives towards encompassing BIM within the working methods of the organization. The current practice of the organization is mainly 2D and 3D CAD designing. The level of experience with BIM is relative small and limited to projects carried out partially with BIM practices. The initiatives for working with BIM are spread throughout the organization due to the lack of common company vision and strategy on this subject. The desired situation within a medium range of time refers to introducing BIM working practices at a level
on which the separate discipline BIM tools with attached data are held in a managed 3D environment with integration performed based on proprietary interfaces. The development of the common view on desired situation for the medium timeframe is motivated by the associated external competition and client demand risks and also by internal direct design benefits for the organization.

In order to create a theoretical approach for analyzing BIM adoption and its challenges, the report presents two sets of theories that are relevant for the research.

The IDT (Innovation diffusion theory) and the TOE (Technology Organization Environment Framework) are theories that provide an analysis basis for technology adoption at organization level. The factors that influence the adoption process in the two theories are complementary, as the TOE is developed based on the IDT and the approach of this analysis are two combine them in a common framework used further. The main categories of adoption factors of the combined framework are Environmental context, Characteristics of the Organization and the Characteristics of the Innovation. Further, individual adoption of ICT can be effectively analyzed through the theory of Adriaanse which states as the main factors for actor’s use of ICT in construction project: personal motivation, external motivation, knowledge and skills and acting opportunities.

From this perspective, the research analyzes the main challenges of BIM implementation within engineering organizations. The proposed grouping of challenges consists of: environmental context challenges (relating to the clients and competition), Organizational challenges (BIM feasibility, implementation management and contractual challenges), Individual adoption challenges and Innovation specific challenges.

BIM implementation within organizations is a change that implies a high degree of complexity and novelty leading to a high number of challenges for the adoption process. The extended challenges list derived from literature review contains in total 24 challenges for BIM adoption. The findings have been overall validated through the case study within the organization members, with some differences due to omission or due to specificity of the projects carried out by the organization. The main challenges for adopting BIM within an engineering organization are:

- Environmental context challenges: insufficient level of clients awareness and requesting of BIM services on projects and level of BIM adoption at industry level.
- Organizational challenges: the extent of the implementation costs correlated with a lack of fast increase in project efficiency for the organization; difficult development of an organizational common policy and set of goals for the new technology; changes required for integration within the business model; the development of BIM modeling skills and associated redefining of staff roles.
- Individual adoption challenges: overcoming individual comfort with familiar working methods and required individual drive towards change
- Innovation specific challenges: interoperability difficulties between project disciplines; scalability of BIM models and compatibility with current systems.

Reflecting on the findings we can observe that the implementation of BIM within an engineering organization is expected to pose challenges which are more social than technical in essence.
7.2 Main recommendations

The second part of the main research question is addressing the main set of recommendations for an engineering organization intending to implement BIM and the structuring of these recommendations within an implementation plan template relevant for the research case.

The BIM implementation challenges presented previously are considered a relevant set of requirements that should be addressed in order to provide an efficient set of recommendations. The proposed set of recommendations for an effective BIM implementation process within an engineering organization relevant regarding the main challenges identified and the project case are presented further.

Start the implementation process with an implementation plan which describes the requirements of the process, the actions to be carried out for addressing the requirements and a clear structure for the process. The BIM implementation plan framework developed throughout this report can consists in a source towards this action. The framework is considered relevant for the case of the commissioning organization. The structure proposed can be used in developing a framework for another engineering organization intending to implement BIM, but the complete framework’s validity should be analyzed through calibrating the set of requirements relevant for each organization.

Establish a BIM initiative group formed by persons representing the tactical decision making level that will further organize the implementation process regarding actions carried out at company level. Developing a BIM feasibility study should be the first aim of the group, addressing the need to analyze the environmental context and relevance of BIM for the organization. The feasibility study should contain reliable information regarding the analysis of market conditions, current and future value of BIM and implementation cost evaluation.

The strategic importance of knowledge on market conditions and future developments is very important as this is the main drive for adopting BIM for engineering organizations. Furthermore, the design benefits are important but more important are the clients’ demands and the competition pressure. Therefore it is highly recommendable for engineering organizations to develop knowledge on market developments on BIM.

Further, an analysis of the prospects of successfully implementing BIM within the organization based on the elements of the ICT-TOE framework is valuable for highlighting potentially hindering or supporting factors for implementation process and adjusting the company strategy and implementation plan accordingly.

Developing a BIM strategy at company level in alignment with the findings of the feasibility study is highly recommendable. It should state the company’s vision in relation with BIM and the strategy and goals to achieve this vision and state principles of collaboration and technology interoperability within the organization. In order to create such a strategy it is very important to gain support from the organization and commitment from the top management regarding the new technology. This action addresses the company level organizational challenges.
Motivated and capable persons which pull the BIM adoption process are the key for success. Continuous internal marketing should be performed in order to increase awareness towards BIM and reason its benefits towards creating a strong support throughout all decision making levels. The internal marketing process should also be used in order to identify persons with high interest for BIM and capacity or potential to contribute to its development at department level towards driving further the adoption process.

At department level, the organizational challenges regarding managing the adoption, the innovation specific challenges and individual challenges should be addressed. The first recommended action is to adjust the business model in order to incorporate the use of BIM. An approach should be selected for generating the revenue necessary for supporting the organization’s effort to develop its BIM capability. This can be done through an increased and adjusted BIM marketing effort based on training client facing staff. Furthermore, the approach for the organization in relation to BIM contracts should be decided upon as indulging in risky or complex projects at the initial phases is not advisable. In time the approach should move towards offering a wide set of services for projects and an integrated capacity, as BIM is most valuable for engineering organizations when it is done for multiple stages of the project.

The second recommendation for the department level actions are is to develop a human and technical resource BIM development plan for achieving the required capability of BIM in alignment with the company strategy and the business model chosen. The plan should allow for a phased buildup of resources in connection with the expected BIM projects carried out by the organization. Further, this approach will allow for evaluating the process and improving it for the further phases. The technical development plan should be made in a future conscious manner, selecting software solutions that are most promising for the long term. Further, it should be based on aspects of interoperability and compatibility of technology. The actual implementation of the plan is to be further carried out at operational level, referring to incorporating the required BIM engineering skills and roles and developing the adequate technical resource according to the plan.

The recommended approach of the BIM implementation plan framework developed in this research is to structure the implementation process actions based on the IDT theory on technology adoption phasing. The proposed phases are: raising awareness, reasoning need for action, decision making, implementing and confirmation. Further, the framework proposes differentiating actions through the required decision making levels (strategic, tactical, operational) at which the actions is carried out. This structure approach indicating responsibility for action and staging the actions based on implementation phasing is considered to provide a good approach towards managing the complexity of the BIM implementation process within engineering organizations.

Currently the commissioning organization is in the phase of developing a BIM initiative group to steer the implementation process at company level and undertakes internal marketing actions. For the short term development of the framework is recommended to develop a BIM feasibility especially focusing on analyzing the market conditions regarding BIM client’s requesting and competition situation. Alongside to analyze the prospects of implementation success based on the combined IDT-TOE framework. The analysis carried out through this report has identified
the external pressure as the factor with largest positive influence, and with potential to have an essential effect, and the innovation characteristics of complexity and compatibility as having the largest hindering effects on the process.

The characteristics of the organization have also a cumulative large hindering effect on the adoption process. These aspects can be addressed and therefore should be considered in order to positively stimulate the process. Having a high degree of positively influencing factors drives the adoption of BIM naturally without the need for a high pressure from the organization and therefore the BIM strategy should look towards ways to change these factors rather than impose the use of BIM. The organizational slack being the organizational factor with the largest hindering effect, the validity of BIM should be considered as an investment for the organization and not a short term perspective. The strategy should also consider the position of the organization in the market and especially in the context of an increasing use of integrated contracting for large construction projects when analyzing the approach.

7.3 Discussion

The current research has developed a set of BIM implementation challenges that are considered to be relevant requirements for an engineering organization intending to implement BIM.

Furthermore, the research has developed structures for analyzing the implementation process within an engineering organization. The ICT-TOE framework describing the factors influencing adoption at organizational level, the framework describing individual adoption factors and the BIM implementation challenges framework are considered valid for any engineering organization addressing BIM implementation.

The BIM implementation plan framework developed based on the relevance of the challenges for the case of the commissioning organization is considered valid for this case. The proposed framework can be considered for adoption cases of engineering organizations but its validity should be analyzed for each implementation case based on the relevance of the challenges for each case. The actions within the plan are therefore suitable recommendations for other organizations with respect to the relevance of the addressed challenges.

For Grontmij, the current report’s contributions are towards forming an overview on the current and desired working practices, the reasoning behind the desire of change and the comprehensive relevance of challenges for the organization. The BIM implementation plan framework is considered to be a valid base for structuring the implementation process within the organization and a source for directions for actions.

The main limitations of the research are the single case study performed and the participation only on the implementation planning phase.

Therefore it is recommended for further research and extensive study on multiple cases in order to validate the framework for engineering organizations and adapt it for a general validity. Further to carry out research during the implementation and confirmation phases in order to verify and improve the framework.
For creating the feasibility study for an organization, the current finding regarding the financial assessment of benefits and indirect costs of BIM implementation are considered insufficiently documented based on the literature study carried out in this research. Therefore methods to assess the efficiency gains and project faults decrease resulted from the use of BIM on projects and a system to analyze the initial decrease of productivity caused by the technology change are recommended to be further researched. These researches are required in order to increase the accuracy and reliability of a feasibility study for BIM.

The strategy for this research project was based on the grounded theory approach, in which a specific plan is developed by starting with a wide view on the topic and systematically narrowing down this view on the specific problems in order to obtain a qualitative and depth research. The approach chosen is consider to have been a good option in order to reach valid results but has resulted in an extensive working method which could have been optimized if the project would have benefited from the current research experience previous to its planning.

The main project objective, detailed in answering the main research questions, is considered achieved. Furthermore the research project is considered to have successfully contributed to the body of knowledge of the research object, BIM implementation. The entire research process has been a pleasant experience for the author and hopefully analyzing the report would have the same effect on its reader.
REFERENCES


Hooper, Martin and Ekholm, Anders. *A PILOT STUDY: TOWARDS BIM Integration - An analysis of the design information exchange and coordination*. 111


## Annex A. Relation between Research Questions and Chapter Numbers

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<td>5.2 Grontmij and its current experience with BIM</td>
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<td>5.3 Current engineering practices of commissioning organization</td>
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</tr>
<tr>
<td>5.4 Desired BIM maturity level</td>
<td>1b</td>
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<td>6.2 BIM implementation actions</td>
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<td>6.3 BIM initiative group actions</td>
<td></td>
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<td>6.4 Strategic level actions</td>
<td></td>
</tr>
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<td>E. Implementation success verification tool</td>
<td>2d</td>
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</table>
# Annex B. Research Material Summary

<table>
<thead>
<tr>
<th>Research question</th>
<th>Research object</th>
<th>Source</th>
<th>Search methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.a</td>
<td>BIM</td>
<td>Literature: Journals, Books (see references)</td>
<td>Electronic search focusing on TUDelft Library’s collection</td>
</tr>
<tr>
<td>1b</td>
<td>Standards and regulations for BIM</td>
<td>Literature: National and industry standards (see reference)</td>
<td>Provided by organization in digital form</td>
</tr>
<tr>
<td>1.b, 1.d</td>
<td>Organization’s view on implementation problems</td>
<td>Individual people: Management specialists Internal documents</td>
<td>Semi structured interviews and documents provided by organization</td>
</tr>
<tr>
<td>1.c</td>
<td>BIM implementation challenges and causes</td>
<td>Literature: Journals, Books</td>
<td>Electronic search focusing on TUDelft Library’s collection</td>
</tr>
<tr>
<td></td>
<td>Conclusions for phase 1</td>
<td>Questions 1.a-1.h</td>
<td>/</td>
</tr>
<tr>
<td>2.a</td>
<td>Requirements formulation</td>
<td>Individual people Management and technical specialists</td>
<td>Semi structured interviews</td>
</tr>
<tr>
<td>2.b</td>
<td>Technology implementation and organizational change theory</td>
<td>Literature: Journals, Books</td>
<td>Electronic search focusing on TUDelft Library’s collection</td>
</tr>
<tr>
<td>2.b</td>
<td>BIM implementation theory and cases</td>
<td>Literature and documents: Journals, Books, Reports</td>
<td>Electronic search and provided by organization</td>
</tr>
<tr>
<td>2.c</td>
<td>Organization view on implementation measures</td>
<td>Individual people: Management and technical specialists</td>
<td>Semi structured interviews</td>
</tr>
<tr>
<td>2.d</td>
<td>Recommended measures</td>
<td>Questions 2.a-2.e</td>
<td>/</td>
</tr>
<tr>
<td>2.e</td>
<td>Evaluation tool</td>
<td>Question 2.1 and Interviews</td>
<td>Semi structured interviews</td>
</tr>
<tr>
<td>3</td>
<td>Implementation plan</td>
<td>Questions 1.a-2.g</td>
<td>/</td>
</tr>
</tbody>
</table>
### Annex C. List of Interviewers

<table>
<thead>
<tr>
<th>Level</th>
<th>Transport and Mobility</th>
<th>Planning and Design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Name</td>
<td>Position</td>
</tr>
<tr>
<td>Strategic</td>
<td>William Harding</td>
<td>Divisiedirecteur T&amp;M</td>
</tr>
<tr>
<td></td>
<td>Ferry Ham</td>
<td>Afdelingshoofd Wegen</td>
</tr>
<tr>
<td>Tactical</td>
<td>Ad van der Velden</td>
<td>Teamleider Infraprojecten</td>
</tr>
<tr>
<td></td>
<td>Aleksandar Milenković</td>
<td>Teamleider Kunstwerken</td>
</tr>
<tr>
<td></td>
<td>Marco Leepel</td>
<td>Teamleider Omgevingsmanagement</td>
</tr>
<tr>
<td></td>
<td>Jan-Hein Poodt</td>
<td>Teamleider Havens, Vaarwegen en Tunnels</td>
</tr>
<tr>
<td>Operational</td>
<td>Arie van der Spoel</td>
<td>Projectleider Infraprojecten</td>
</tr>
<tr>
<td></td>
<td>Björn Nijzink</td>
<td>Engineer Infraprojecten</td>
</tr>
<tr>
<td></td>
<td>Evert Lans</td>
<td>Groepsleider Kunstwerken</td>
</tr>
<tr>
<td></td>
<td>Idoia Martinez</td>
<td>Engineer Kunstwerken</td>
</tr>
<tr>
<td></td>
<td>Martijn van Drunen</td>
<td>Adviseur Assetmanagement Consulting</td>
</tr>
</tbody>
</table>
Annex D. Implementation success verification tool

This section addresses research question 2d. *What is a good set of criteria and associated weight factors for a multi-criteria analysis regarding the successful implementation of BIM within the commissioning organization based on the perception of stakeholders?*

The desired outcomes of each action presented in sections 6.3, 6.4 and 6.5 are an appropriate set of criteria for analyzing the action’s success. Associated weight factors are computed based on the relevance of the challenges addressed and the degree of challenge mitigation of each action. The scoring should be done according to the opinion of the BIM strategic support group regarding company level actions and progress and of the department management for actions regarding department level implementation.

Table 8 Multi criteria analysis for BIM implementation verification

<table>
<thead>
<tr>
<th>Action</th>
<th>What - Desired Outcome</th>
<th>Relevance factor</th>
<th>Progress Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Reliable information regarding market conditions, value of BIM, future prospects and implementation cost evaluations</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Raise awareness on BIM and present time pressure to change; reach a common view on the technology; identify BIM champions; gain support of top management.</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>Counsel the Department implementation groups towards developing required actions</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Company vision and strategy, principles on technology, company BIM Goals</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Monitoring implementation at company level, allocate support resources, enable BIM initiative group</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Identify and enable at least one person at tactical level and one at operational level for each department to develop the department implementation plan and steer the internal process</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>Decide on approach to develop the BIM capability of the department, develop BIM marketing skills and analyze BIM contracts</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>Decide on pace and goals for the implementation process and verification process</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3.3.1</td>
<td>Analyze current and required department human resource and functions and develop training plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3.2</td>
<td>Decide on BIM software solution, analyze requirements for achieving it and plan technical resource development accordingly; enable data exchange system and object library</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>Convince organization members of the benefits of developing BIM skills and the time pressure to change</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Provide a structured plan for BIM use in projects describing responsibilities, deliverables, level of detail and model management</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Develop human resource according to implementation plan</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Develop technical resource according to implementation plan</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Plan</td>
<td>Overall progress</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The progress scoring should be made on a scale from 1-5 for reaching the desired outcomes of each action and the general implementation plan overall progress computed as the percent of the weighted scores of total sum achieved.

An alternative BIM implementation analysis progress verification tools to be considered is the BIMSCORE system (Kam, et al., 2012) which offers a quantitative measurement of implementation success, rather than the qualitative approach (see Figure 1Figure 35) of the progress success presented in this report.

Figure 35 BIMSCORE system - quantitative measurement of BIM implementation success (Kam, et al., 2012)
Annex E. Registered benefits of BIM usage in performed projects, examples

A significant gap in BIM benefits literature consists in their translation into figures which can reflect the actual profit increase which such a work practice brings. This section will look on some registered translations of BIM usage benefits into cost reduction of projects.

1. The first example is the Letterman Digital Arts Center (see Figure 36), an 80,000 m² arts center and theater constructed between 2003 and 2005 in San Francisco. The project was commenced using traditional design practices and BIM adoption was done in the post design phase. Although most of the design documentation was in 2D, the project registered high benefits from BIM using. The benefits came in the forms of discovering design flaws before constructing, resolving coordination problems, accurate positioning of pipes through specialized software connected to the building model, simulation of emergency situations, 4D time based construction planning and animation on which the 5D cost estimation and scheduling was created. The estimated savings resulted from BIM use and addressing only the construction phase were of $10 mil for the total project cost of $350mil. (2.85%). The author also stresses that the real value of using BIM processes lies in the sharing and integration of information with multiple end users, designers, contractors, suppliers through the life cycle of the project. (Borysławski, 2006)

2. Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM indicates benefits such as (CIFE, 2007):
   - Up to 40% elimination of unbudgeted change.
   - Cost estimation accuracy within 3%.
   - Up to 80% reduction in time taken to generate a cost estimate.
   - A savings of up to 10% of the contract value through clash detections.
   - Up to 7% reduction in project time. (Azhar, et al., 2012)
3. The data for this case study is provided by Holder Construction Company, Atlanta, Georgia. The project details are as follows: (Azhar, et al., 2012)
   - **Project name**: Hilton Aquarium, Atlanta, Georgia
   - **Project scope**: $46M, 484,000 SF hotel and parking structure
   - **Delivery method**: Construction manager at risk
   - **Contract type**: Guaranteed maximum price
   - **Design assist**: GC and subcontractors on board at design definition phase
   - **BIM scope**: Design coordination, clash detection, and work sequencing
   - **File sharing**: Navisworks used as common platform
   - **BIM cost to project**: $90,000 - 0.2% of project budget ($40,000 paid by owner)
   - **Cost benefit**: $600,000 attributed to elimination of clashes
   - **Schedule benefit**: 1143 hours saved
### Annex F.  BIM Effort Distribution per Project Phase

<table>
<thead>
<tr>
<th>DSF Project Phases</th>
<th>Alternative Project Phases</th>
<th>Description of A/E BIM work effort</th>
<th>Traditional work effort</th>
<th>BIM work effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-design (agency work but confirmed by A/E during pre-contract phase)</td>
<td>Conceptualization</td>
<td>Confirms program, budget and schedule at a high level</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Peer review</td>
<td>Criteria Design</td>
<td>Defines the optimum design solution meeting program, budget and schedule.</td>
<td>10% 10% total</td>
<td>15% 15% total</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>Detailed Design</td>
<td>Facility design is fully developed, coordinated and validated. Cost and Schedule established with high level of precision.</td>
<td>25% 35% total</td>
<td>30% 45% total</td>
</tr>
<tr>
<td>Final Design (100% review)</td>
<td>Implementation Documents: Review</td>
<td>Detailed design is fully annotated and graphically clarified for accurate bidding, scheduling and construction purposes.</td>
<td>40% 75% total</td>
<td>30% 75% total</td>
</tr>
<tr>
<td>Bid set</td>
<td>Implementation Documents: Bidding</td>
<td>Above plus inclusion of review into model(s)</td>
<td>In above</td>
<td>In above</td>
</tr>
<tr>
<td>Bidding</td>
<td>Buyout</td>
<td>Clarify document intent</td>
<td>5% 80% total</td>
<td>5% 80% total</td>
</tr>
<tr>
<td>Construction Issue</td>
<td>Implementation Documents: Construction</td>
<td>Above plus inclusion of addendum into model(s)</td>
<td>In above</td>
<td>In above</td>
</tr>
<tr>
<td>Construction</td>
<td>Construction</td>
<td>Maintain Implementation model(s)</td>
<td>20% 100%</td>
<td>20% 100%</td>
</tr>
<tr>
<td>Closeout</td>
<td>Closeout</td>
<td>Record documents, change orders and other appropriate close-out submittals incorporated into the model(s)</td>
<td>In above</td>
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Figure 37 BIM Effort Distribution per Project Phase (Napier, et al., 2009 p. 27)
Annex G. Decision making levels linked with organization positions

Throughout the report the decision making levels within an organization where referred to. This list presents the linkage with the organization positions as they were used.

Strategic level: CEO, CFO, Division directors
Strategic – tactical level: Department heads
Tactical level: Team leaders
Tactical – operational level: project managers (or similar)
Operational level: designers, advisors (or similar)

Strategic management concentrates on the performance of the complete organization. The focus here is to determine the most appropriate objectives that the organization should pursue given its internal strengths and weaknesses as well as the external opportunities and threats faced by it. Strategic management involves achieving balance between requirements of different functions and units of the organizations. It also involves balancing risks in short and long term. Based on these considerations strategic management determines long term objectives to be pursued by the organization and identifies the ways and means of achieving these objectives. One unique characteristic of strategic management is the absence of any higher level plans or objectives to guide strategic management action.

The level between the strategic and operational management is the middle management level. Some authors also call it tactical management. This level of management is concerned with planning and control for individual organizational functions such as marketing, production, and HRD, or sub function within them, for improving performance in short or medium term. Tactical managements are termed as intermediate management. They have lower authority than strategic management. Tactical management involves making decisions about how an organization should go about achieving the overall objectives determined by strategic management. Tactical management decides what needs to be done within that year to implement the plan of strategic management.

Operational management lies at the other end of the continuum of management levels. It is concerned ensuring that the day to day operations of the organization are carried out effectively and efficiently. For example, operational management will concentrate on ensuring that workmen on the shop floor are instructed correctly on the jobs to be performed by them at any particular time and that they are provided with required material, tools and other facilities to get on with the work.
Annex H. Simplified alternative requirement list based on groups of challenges

Based on the challenges relevance presented in the previous section, we can extract the core requirements for adopting BIM within an engineering organization. The requirements represent a combination of the closely linked challenges.

**Requirement 1: External demand (clients) and/or pressure (competition)**

The first requirement combines the two relevant environment challenges, demand for BIM from clients and pressure to use BIM due to competition. At least one of this two should be true in order to successfully reason the use of BIM in a context where the direct benefits are not steering the implementation process. The two parts are combined because they are interlinked, as the pressure from competition is in high connection with the demand from clients, the two influencing each other. This requirement can be influenced in a limited amount by organization, thus having a large degree of independence from the actions of the organization.

**Requirement 2: Internal awareness of BIM and support for implementation process**

This requirement groups the challenges referring to the awareness of BIM and its potential, the financial feasibility of implementing BIM and the structuring of the BIM implementation process. The challenges connected in this requirement are O1, O2, O3, O4, O5 and O7. The reasoning refers to the need to become aware of the new technology, become convinced of its benefits, decide on what should be done and support the adoption process. Therefore this requirement is very much related to the individual adoption of technology factor and is mainly a social process.

**Requirement 3: Adequate human resource and processes for working with BIM**

This requirement groups the challenges referring to the human resource required for working with BIM. Therefore, as the previous one referred to the support for the implementation process, this requirement refers to the capability of working with BIM. It combines the challenges O6, O8, O9, O10, O11, O12, O13 and O14. Thus it addresses the challenge of introducing new functions and new skills to the project teams and become capable of working in the new paradigm, and become able to market the new capability and make adequate contracting. This requirement refers therefore to knowledge and skills gaining and organizing the processes.

**Requirement 4: Adequate technical means for working with BIM**

Requirement 4 addresses the group of innovation specific challenges. Therefore it addresses finding the adequate technical solutions for the organization and making them available. Adequate refers to compatible and interoperable software solutions, with a comprehensive customizable object library and hardware capable of running and storing the BIM models. Thus this requirement incorporates innovation challenges 1 to 5.
Annex I. List of frequently used abbreviations

BIM - Building information modeling
IFC - Industry Foundation Classes
IFD - International Framework Dictionary
IDM - Information Delivery Manual
iBIM - Integrated BIM
CPIC - Construction Project Information Committee
AIM - Architectural information model
SIM - Structural information model
FIM - Facilities information model
BSIM - Building services information model
BrIM - Bridge information model
AEC - Architecture Engineering and Construction industry
TOE - Technology Organization Environment Framework
IDT - Innovation Diffusion Theory
COBie - Construction operation building information exchange
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