Work Breakdown Structure as a method for planning and control at Nijhuis Bouw

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Management summary

We have conducted this research on behalf of the IT department of Nijhuis Bouw, a construction company. It aims to improve the planning and control aspect of projects carried out according to the Trento Construction concept, from a technological perspective. The Trento concept is a standardized form of construction developed by the company itself. Options in the construction of houses are limited by Trento to improve the efficiency of the process.

We have identified little grip on project schedule development and project control as the problem that Nijhuis Bouw is currently facing. The company has the aspiration to check the status of construction projects real-time and to develop project schedules automatically. We have seen that the company currently uses a planning and control method that does not fit their future aspirations. Therefore, Nijhuis is in need of a fundamental method for planning and control that supports their ambition.

Nijhuis is currently using two tools to create project schedules, one to create an overall schedule and one to communicate deadlines and responsibilities with subcontractors. Their desire is to combine these functionalities in addition to status checking and schedule generation. Therefore, we have selected a method for planning and control and we have analysed its possibilities in order to prove its suitability for the company.

In order to find a suitable method for planning and control for the company, we have researched the scientific literature. After selecting a suitable method, we have conducted a more in-depth research to get a better understanding of the concept and select the layout that fits the company. To investigate whether benefits of the selected method also exist in the Trento process, we have examined the resemblance between literature and practise. We have analysed project schedules and created a business process model to validate the outcomes. In order to shape the selected method towards a concept that is usable for status reporting and schedule generation, we have created a data model. This data model represents data fields that should be recorded when implementing the selected model. After assessing the outcomes, we have drawn our conclusion and point out topics for further research.

The literature has pointed out two types of methods: beginning-to-end-planning and top-down planning. After reviewing both methods, we have selected the top-down planning method, also known as the Work Breakdown Structure, as a suitable planning and control method for Nijhuis. Further investigation of the literature has brought various insights. Multiple WBS styles have been reviewed and a product-oriented WBS with a deliverable oriented formulation has been selected for Nijhuis. In addition, the literature has pointed out the term Constrained Work Packages, an elaboration on normal Work Packages, the lowest elements of a Work Breakdown Structure. Constrained Work Packages are enriched with constraints following from activities in a process. By conducting the scientific literature, we have proven that Constrained Work Packages are a solution for both project control and automatic schedule development.

In order to prove that Constrained Work Packages also exist in the current Trento concept, we have created a business process model of the Trento process. Therefore, the resemblance between the theory and practice of the Trento Concept had to be proven. Multiple finished projects were compared with the Trento template and resemblance with the reality has been proved.

To identify Constrained Work Packages in the Trento construction process, a business process model has been created. First a general overview of the entire process was made, after which an in-depth version that proves the existence of Constrained Work Packages, could be created. By modelling an interval of the Trento process, we have established constraints and relationships between activities. Using this in-depth model and its explanation, we have pointed out the potential value of Constrained Work Packages as a tool for automatic schedule generation and status reporting for Trento projects.

After identifying the existence of Constrained Work Packages in the Trento Construction process, we have investigated a way to implement this method for automatic schedule generation and

status reporting. To shape this method towards the company's desires, we have created a data model for Constrained Work Packages. We have selected the Entity-Relationship Diagram (ERD) to model the data fields necessary to record Constrained Work Packages. In consultation with the company, we have formulated three requirements for a work package in a digital environment to construct the data model. Afterwards, we have assessed the data model on these three criteria. We have created the data model in three steps: a conceptual data model, a logical data model and a physical data model. In order to create the final data model, we have identified relevant data fields. We have selected data fields from a literature analysis and their current scheduling tool and validated the data fields using a stakeholder analysis.

We conclude that a product-oriented WBS with a deliverable-oriented formulation is a suitable method for planning and control for the Trento Concept at Nijhuis Bouw. The literature states that project control can be enhanced by tracking work packages and the method supports automatic schedule generation by setting up a network of Constrained Work Packages. We have proven that the Trento Concept represents the reality and that the process consists of Constrained Work Packages, which has pointed out the value of this concept for Trento. Finally, we concluded that a data model for a Constrained Work Package in the Trento environment can be set up, in order to shape this method towards the company's desires. Finally it was established that there are several fields left for further research before this concept can be put into practise. The analysis of the process for the creation of multiple buildings has been pointed out as an interesting topic of investigation. In addition the sizing of a work package was stated in the literature as an essential aspect of WBS and is yet to be defined for Trento.

We have proven that WBS is a suitable solution for the Trento department of Nijhuis Bouw. Now that we have justified the method for planning and control, further research on from a practical perspective has to be conducted. For automatic schedule generation, more research has to be done on the functioning of a network of constrained work packages. Regarding the status reporting, more research should be done on what is to be reported and how this should be done. Therefore, research on work package sizing and communication methods is required.

Preface

This report is written in order to complete the bachelor of Industrial Engineering & Management at the University of Twente. The bachelor thesis has been carried out at the IT department of Nijhuis Bouw and focusses on the Trento Construction concept. As the report is finished I would like to use this section to express my gratitude and appreciation to the people who supported me throughout this experience.

First, I would like to thank my supervisors Ipek Seyran Topan and Erwin Hans. Ipek, I admire your patience and infinite cheerfulness and I want to thank you for your sincere interest in my academic progress as well as my personal well-being. Erwin, thank you for giving me the confidence I needed for this challenge and for the great conversations about personal development and fishing trips. Your personality displays so much positivism which provided me with the right motivation to carry on the research at times when I needed it the most. I could not have wished for a better supervisor.

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Enjoy reading my thesis!

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Acronyms

BIM Building Information Modelling.

BPM Business Process Model.

BPMN Business Process Model and Notation.

BTO Build-to-Order.

CPM Critical Path Method.

CWP's Constrained Work Packages.

DSRM Design Sciene Research Methodology.

ERD Entity-Relationship Diagrams.

ERP Enterprise Resource Planning.

KPI's Key Performance Indicators.

MTO	Make-to-Order.
RBS	Resource Breakdown Structure.
SBS	System Breakdown Structure.
UI	User Interface.
WBS	Work Breakdown Structure.

1 Introduction

1.1 Company Introduction

Nijhuis Bouw B.V is a large, versatile construction company with great ambition for innovation. Currently they have 5 different offices spread over the higher eastern part of the Netherlands. Next to new construction, the company also provides renovation and customized projects. Nijhuis Bouw can be roughly divided into three departments: Trento construction, Trento renovation and tailor-made construction. In addition, Nijhuis has a sister company that supplies carpentry work for facades to their construction sites, among other things. Nijhuis constructs houses and flats, mainly by order of housing associations.

In order to keep up with the competition in the construction industry, Nijhuis's goal is to automate their construction process and the management of its construction activities. To be able to realize this, the company tries to look at construction projects from a production company's perspective. This research focuses on Trento construction, a method in which predesigned house types are being built rapidly by means of a process that has been kept basic because of less freedom in the possibilities for the predesigned houses. Also, several elements necessary for construction are prefabricated before arriving at the construction site.

In the ideal situation, the construction process is standardized from start to finish and is as automated as possible. Clients can select the types of houses they want and that information is sent straight to the Enterprise Resource Planning (ERP) of Nijhuis, which is defined by Blackstone Jr. and Cox 2005 as a framework that organizes, defines and standardizes business processes necessary to effectively plan and control an organization. This way organizations can use their internal knowledge to seek external advantage. For Nijhuis, this system should then generate an optimal schedule, a vital step in the vision of Nijhuis. In addition, resources should be automatically ordered in time and progress could be checked real-time. There is a long way to go until this ideal image is reality. However, currently a suitable method for scheduling and control that will become a fist step in carrying out this vision, is necessary. This method will lay a foundation for the development of their automation aspirations.

Along with this vision of a construction company as production company, Nijhuis is going to implement a new ERP system that contributes to achieving this goal. Nijhuis desires to embed the method for planning and control into the new system. This will give them more grip on process management and assists in automatic schedule generation, an important future goal of the company.

1.2 Problem Identification

1.2.1 Action problem

Construction projects require a lot of management to guide them to a successful ending. Next to discussing the client's desires and the project's requirements, permits have to be acquired and an executor planning is created. On top of this, the project is constantly subject to new desires of both the client and the residents and is carried out by numerous employees who have to be correctly instructed. Automatic schedule generation and the automation of other tasks involved in such a complex process is a challenge, because construction projects are subject to unpredictable factors like suppliers, absenteeism and weather conditions. Therefore, the scheduling and monitoring of these projects becomes difficult.

In order to get more grip on the construction process, Nijhuis currently uses two different scheduling tools: PowerProject and KYP Project. PowerProject supports planners of Nijhuis to create the step-by-step planning for a construction project, from site preparation to delivery. It focuses on the visualization of the complete project. KYP provides a clear overview of: the particular tasks that has to be to be completed, the due date and especially who has to perform the task. For the execution of projects, Nijhuis hires different subcontractors called co-makers. Co-makers are a specific group of partners of Nijhuis who cooperate with them in many projects. KYP enables Nijhuis to cleary assign co-makers to tasks, therefore the system currently plays an important role in their project management.

Both scheduling tools provide a good insight in running construction projects. However, even though PowerProject gives insight into the tasks that need to be performed and KYP allocates these tasks to the co-makers responsible, an integrated overview of the status of a project is missing. Usage of the two tools creates ambiguity amongst employees. Hence Nijhuis wants to tackle this problem by using a new ERP system that integrates these functions and can adopt a suitable method for scheduling and control.

In order to successfully switch from a project-oriented to a production-oriented strategy, Nijhuis needs to get more grip on project schedule development and project control. Therefore, *"little grip on project schedule development and control"* is the selected **action problem**.

1.2.2 Problem cluster and core problem

After identifying the action problem, this section looks at its underlying causes. This is done by creating the problem cluster, shown in Figure 1.

Three different reasons that inhibit the scheduling and controlling abilities have been identified. The first one is a lack of integral oversight in construction process. Even though both current scheduling tools individually provide insight in their own fields, an integrated overview remains missing, which causes chaos and opacity within the company.

The second problem is the lack of accessibility of project status. An up-to-date status supports the identification of bottlenecks and risks in the process. Inaccessibility of a project's status complicates the controlling aspect of project management.

An underlying cause of these first two problems is the fact that the tools currently used by Nijhuis, are not integrated with their ERP system. The company stresses that the combination of using different tools and a separation of those tools from the ERP system negatively influences both the oversight in the construction process and its accessibility.

These problems come together in the fact that there is currently no clear and suitable method for project planning and control embedded in the process of Nijhuis Bouw. As mentioned, the company is trying to realize their vision of automating their business processes. This particular method should provide structure for the company in terms of planning and control and should be compatible with future development of Nijhuis. So, in terms of planning, automatic planning generation should be a feature that could be realized based on this method. Regarding control, Nijhuis should be able to track their project on progress. Hence the selected **core problem** for this research is that the company does not have a suitable method for project planning and control. The third problem concerns stochasticity in construction project. As mentioned earlier, construction projects are subject to a lot of uncertainties. A common way to deal with these uncertainties is to create buffers in the project schedule. However, buffers can be expensive and shifting towards a make to order production approach instead of maintaining a project-oriented strategy requires scheduling that limits this stochasticity and thus the necessity of buffers.

This stochasticity can be split into two categories: controllable and uncontrollable factors. A controllable factor could be the selection of a supplier and an uncontrollable factor could be weather conditions. The model is still superficial regarding these stochasticity factors. This is due to the fact that in cooperation with the company it is decided that a solutions should be found in the direction of a method for planning and control. Therefore, these factors are considered out of scope.

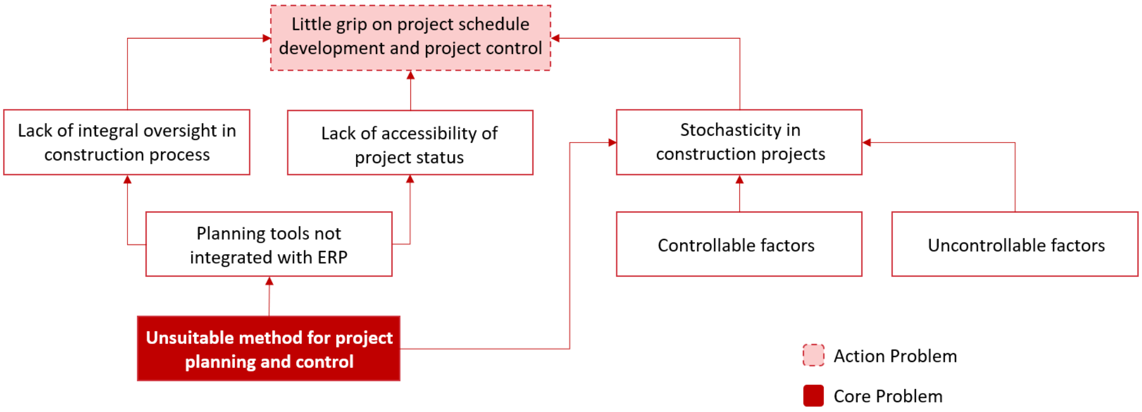


Figure 1: Problem Cluster of Nijhuis Bouw

2 Research Design

2.1 Research Approach

To solve the problem identified, the Design Sciene Research Methodology (DSRM) introduced by Pfeffers 2007 will be used (Figure 2 DSRM process model). This method provides a systematic approach toward a solution for a design-oriented problem. The company's desire is to adopt a method for planning and control of which, after a short selection phase, an implementation design has to be created. Thus, the DSRM method applies in this situation and is therefore a good starting point to tackle the problem at hand. The DSRM consists of 6 phases, the nominal process sequence, which will be elaborated on in this section.

1. *Identify problem & motivate*
   In this first phase the company's problem needs to be identified and motivated. This is performed in section 1.2.1 Action problem and section 1.2.2 Problem cluster and core problem.

2. *Define objectives of a solution*
   In the second phase the goal and its requirements need to be discussed. Since the research is done on behalf of the company, they play a significant role in the determination of requirements. Interviews with different employees will be conducted to gather requirements of the system. In addition, literature will be studied for this purpose. While generating requirements, the feasibility should be kept in mind.

3. *Design & development*
   The third phase the focus is on creating the artifact, the method. In this research the artifact is not a stand alone element. Its development will be supported by both a literature study on the concept and a Business Process Model (BPM), which provides insight in the process, useful for the design of a solution.
   In addition, in an attempt to enhance the value of a planning and control method for Nijhuis, data fields that should be recorded for its functionality will be identified and modelled using an entity-relationship diagram. These models will be discussed in section 4 A Process Model and 5 A Data Model for Work Packages.

4. *Demonstration*
   The demonstration phase serves as a moment at which the preliminary design will be presented and feedback is received. Important in this phase is to assess in what way the designed artifact tackles the problem. Design choices must be explained in detail to ensure the usefulness of the feedback. During this research multiple demonstrations will be given, since apart from a selected method, the two models also need to be validated.

5. *Evaluation*
   After assessing how the artefact solves the problem at hand, the evaluation phase is concerned with the extend to which the artefact solves the problem. This is done by evaluating whether the objectives established in phase 2 have been accomplished. If the extend to which these objectives are being accomplished is insufficient, the DSRM model iterates back to either phase 2 or 3, to revise the objectives or redesign the artifact.

6. *Communication*
   In the final phase of the DSRM, the research and its results are communicated. The problem at hand, the designed artifact and the way this artifact contributes to solving the problem must be made clear. The phase serves as a concluding step that informs others about knowledge gained by the conduction of the research.

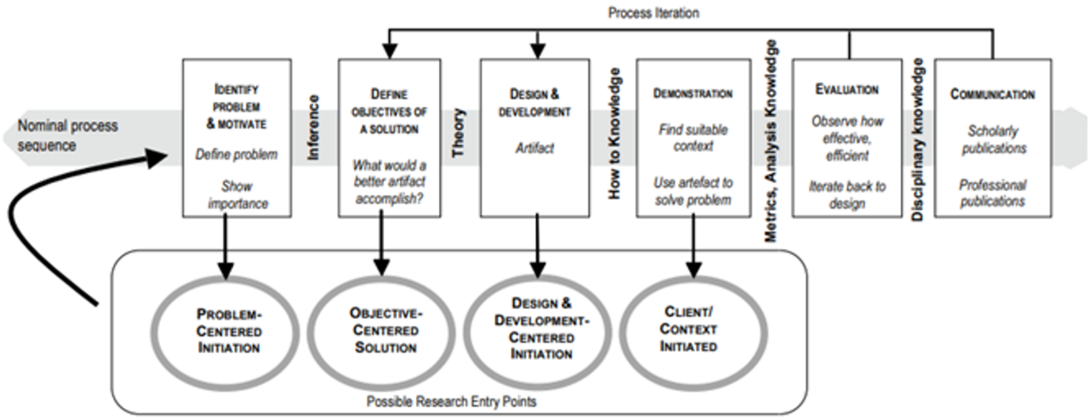


Figure 2: DSRM process model

2.2 Scope

To position this research among different types of planning, we use the planning framework for make-to-order environments found in Hans et al. 2011. The method originally came from Giebels 2000 and consists of a decomposition of the planning in three hierarchical levels vertically, as proposed by Anthony 1965. In addition, Giebels 2000 decomposes the planning types by three categories of planning tasks horizontally, creating a three by three framework. Figure 3 shows where this research positions itself within the framework. It has been slightly adapted; because the research is done in the construction sector, we will use *construction planning* instead of *production planning* in the framework of Giebels 2000.

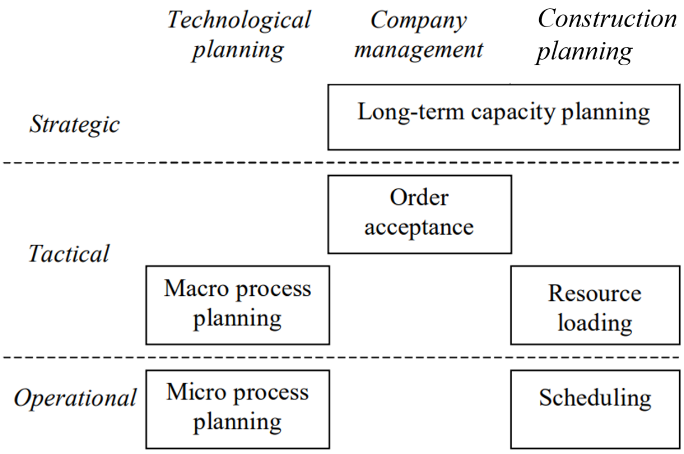


Figure 3: A framework for a make-to-order environment, from Giebels 2000

The research serves as a proof of concept for the implementation of a method for planning and control. It is aimed at proposing a solution that supports the company's desires. These are: automatic schedule generation and a feature that shows the progress of construction projects. So, we do not focus on the actual creation of a schedule or the development of such a feature.

This research positions itself in the *scheduling* field. Implementing a method for tracking and allocating work packages (a term which will be elaborated on in section 3) can form a basis for a scheduling operations concept, when capacity constraints are added. Addition of capacity constraints to the schedule generation and the project progress feature, is a matter for further research.

Nijhuis has three departments: Trento Construction, Trento Renovation and a department for customized solutions. The nature of the Trento construction method makes it more suitable for researching a scheduling and control method. Therefore, the scope is limited to this department.

The Trento construction concept is a Make-to-Order (MTO) production approach. In a MTO approach, products are only built when a received order is confirmed, as opposed to Build-to-Order (BTO), in which the parts needed for the product are already available for assembly (Gunasekaran and Ngai 2005). MTO is used for either highly customized or low volume products (Hendry 1998). When a client's order is confirmed, several parts of the houses, like walls, are prefabricated in a factory and are transported to the construction site, also known as a fixed position layout (Ozcan 2005). The Trento construction concept has a reduced product variability, due to limited options in prefrabication. This makes different construction projects more comparable from a planning perspective. Hence, Trento construction is the selected department to perform the research.

The research will be based on schedules of construction projects for rental houses. Tenants have less customization options for the house, while buyers of a Trento house could add features like a dormer. The aim of this research is to find a method for planning and control and to investigate what an implementation at Nijhuis would look like at an early stage. Taking customization options into account would unnecessarily complicate the research. Therefore, homes for sale are out of scope.

2.3 Stakeholder analysis

In order to find a suitable solution for the company, a stakeholder analysis is performed. This analysis identifies people who could benefit from the outcome of this research. Throughout the research, decisions made will be based on what is best for the stakeholders. Stakeholders have a prominent role in research following the DSRM, because they are the focus point when designing a solution. Later in this research, we will go back to this analysis when we create a data model in section 5. The stakeholder analysis can be found in Appendix E.

2.4 Deliverables

This research serves as an investigation of what method for planning and control would be best for Nijhuis Bouw. The main deliverable will be an advisory report on what method to adopt and how to shape its implementation. This advisory report will evaluate the selected method while keeping the future goal of the company in mind. Essential elements necessary for correct implementation of a method for scheduling and control will be identified and explained.

The advice for a suitable method and its implementation will be supported by a process model. This visualization helps establishing the chronological order of activities and their relationships. The process model also helps with comparing theories from the literature to the reality of the Trento process.

In addition to the process model, a data model is also constructed. This data model forms a basis for the implementation of the method for planning and control selected in this research.

2.5 Research Questions

The main aim of this research is to find a method for planning and control that is suitable for the Trento Construction method at Nijhuis Bouw. Additionally we need to investigate how this method could be implemented best. Hence the main research question is:

How should a new method for planning and control be shaped to fit the needs of the Trento Construction concept at Nijhuis Bouw best?

To solve the main research question, it is broken down into sub questions, which are elaborated on below. These questions form the common thread throughout the bachelor thesis and will provide guidance through the process of answering the main question step-by-step.

1. *Which existing method or theory on in the scientific literature for the development of a method for planning and control is suitable for Nijhuis Bouw?*
   The answer to the first question follows from a literature study. This will give a better understanding of what methods for planning and control exist in the literature. The outcome is a suitable method. This method then serves as a framework in which a solution should be found. Possibilities will become clear and opportunities to incorporate company requirements can be identified.

2. *How could the current Trento Construction process be modelled in a process model?*
   The creation of a process model of the construction process forms a foundation for this research. For this process model, multiple schedules of completed projects will be compared and overlapping activities will be extracted. This then leaves the most common steps involved in the process that will be mapped in the model. Before the process can be mapped, different modeling methods need to be review in order to find the most convenient one.

   The model supports the visualization of relationships between activities, which is helpful for validating the applicability of the selected method for planning and control. Additionally, the BPM serves as a great first step in the direction of the creation of the entity-relationship model (knowledge question 3). Entities and data streams can be both deduced and validated using the BPM.

3. *What would a data model of a Constrained Work Package look like?*
   In order to establish the entity-relationship diagram for the Trento Construction process, another good look will be taken at the BPM. This model of the previous step already contains several entities and displays its relationships. From these relationships, essential data streams are identified and placed in the entity-relationship diagram.

   This model contributes to the determination of what data should be recorded by Nijhuis to support and monitor the construction process and thus helps providing a tailored advice.

4. *What conclusions can be drawn and what recommendations can be given based on the results?*
   After generating a solution for the Trento Construction process it needs to be evaluated. This last knowledge question will cover what can be concluded from the research, discusses limitations and identifies topics for future research.

3 Work Breakdown Structures literature study

This first subsection, identifies scheduling and control methods for Nijhuis, compares them and argues which one is most suitable for the company. After selecting the methodology called Work Breakdown Structure (WBS), a definition of the construct is given along with definitions of elements related to a WBS. The literature review provides information on the definition, function, related elements and the decomposition of the WBS. After closely reviewing the articles from a construction company's perspective, the relevant findings are elaborated on, providing the framework that can be used to develop a WBS.

3.1 Scheduling and control method selection

Construction projects are complex and time-consuming. A wide variety of skills are required and projects are subject to unpredictable factors. At the basis of project management, is a proper planning. Sears et al. 2015 define planning as *"the process of devising of a workable scheme of operations that, when put into action, will accomplish an established objective"*. They state that construction planning consists of five steps:

1. Determining the general approach to the project
2. Breaking down the project into activities
3. Establishing relationships between activities
4. Visualization of the planning information in the form of a network
5. Endorsement by the project team

In Trento Construction, this first step is quite straight forward. The construction method is built around predesigned houses which can be selected by the client. The client then has different options to customize these designs. This already serves as a general project approach.

The next three steps are more challenging for the company. Currently there already exists a breakdown of activities in their project plan. However, this breakdown is made some time ago and it is uncertain whether this particular breakdown is compatible with a new ERP system. In addition, relationships between activities in the construction process have not been established in a clear manner yet. Experienced employees know a lot of the relationships by heart. However, visually represented relationships that could be used in automatic schedule generation are missing.

Sears et al. 2015 presents two different planning methodologies: beginning-to-end planning and top-down planning. Beginning-to-end planning breaks down the complete process into steps or activities, from start to completion. To formulate these steps, a level of detail is required. This level could be presumed or could be determined by starting with limited detail and add detail until the desired amount has been reached. New steps or activities are logically derived from formulated ones in a chronological order, which makes it a somewhat intuitive method.

Some projects are so complex that the determination of the sequence of activities is difficult. These project could benefit from a beginning-to-end planning, because this method does not make the project manager face unnecessary challenges like creating a perfect sequence. However, there are two downsides of this method. First, members of the team might not agree on the level of detail that is demanded by the project. Second, it could happen that the planning team leaves out entire categories of operations, resulting in an inaccurate estimation of the required completion time.

Putting this planning methodology into the perspective of Trento Construction, it does not classify as a suitable option. As mentioned earlier, Nijhuis is shifting towards a make-to-order construction process. The main advantage of a make-to-order layout is the reduction of variability of the end product, which enables standardization of the process. This switch in project approach demands for a planning methodology that allows optimization. In other words a planning methodology that requires you to work towards an optimal sequence of activities.

Sears et al. 2015 also presents the top-down planning methodology, which is often referred to as Work Breakdown Structure. WBS starts with the complete project scope and then breaks it down into its major deliverables, which in their turn are broken down into smaller elements. This breakdown could be performed on various characteristics of the task. Examples proposed in the literature are: breakdown by equipment requirements, subcontractor responsibilities or distinct structural elements.

Working with a WBS has significant advantages according to Sears et al. 2015 and is therefore preferred in the construction industry. A deliverable orientation provides a solid basis for project planning as it serves as a referencing point. It also supports the division of responsibility. The smallest tasks in the hierarchy, often referred to as work packages, can be easily divided among subcontractors when properly defined (Ministry of Infrastructure and Environment 2013). In addition to facilitating the planning process, WBS has several other applications like cost reporting, the creation of hierarchy reports and the Critical Path Method (CPM) Sears et al. 2015. CPM is a scheduling algorithm that generates a project schedule based around the longest path of dependent activities. The CPM is frequently used in the construction industry. For the execution of this algorithm, work packages of the WBS are used to estimate the required time. So the method is also compatible with automatic schedule generation. In addition, CPM also requires the creation of a relationship model for which the work packages can be used to derive activities from.

Leidraad voor Systems Engineering binnen de GWW-sector, a document publised by the Dutch Ministry of Infrastructure and Environment (Ministry of Infrastructure and Environment 2013) in cooperation with several other parties that reviews development in the ground, road and water construction sector, also uses WBS. The methodology is proposed as a useful instrument in project realization. After identification of the stakeholders Ministry of Infrastructure and Environment 2013 proposes a System Breakdown Structure (SBS), which is a limited hierarchical representation of the project scope. Later on, this SBS will be further developed in a detailed final version, the WBS.

This fundamental planning methodology fits better into the vision of Nijhuis. The similarity of the Trento Construction projects lends itself for a breakdown of a general planning, which could then be optimized. The smallest elements of the breakdown also contribute to the control aspect of project management, since those elements make it easier to check the project status.

After consultation, Nijhuis also shared their preference for this methodology. In their opinion the development of a WBS for Trento Construction lays a foundation for future automation aspirations, like schedule generation and resource ordering based on tasks extracted from the WBS.

In conclusion, the literature suggests the usage of WBS for the support of project planning and control instead of a planning methodology based on phases. This is also in line with the preference of Nijhuis, who thinks the WBS is a more future proof option. Therefore WBS is selected as the planning and control method for which the implementation at Nijhuis for Trento Construction will be researched.

3.2 WBS development

Now that a scheduling and control method is selected, we will further analyse it to get a better understanding on what the concept WBS entails and what is necessary for a proper implementation.

3.2.1 Functionality

The concept Work Breakdown Structure was introduced by the U.S. Department of Defense and NASA (Cleland 1964). The concept was developed to support the planning and control of extensive projects. Through the years, various industries have started to adopt the concept and it has become a foundation for project management.
Project Management Institute 2004 defines a WBS as: *"a deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables. It organizes and defines the total scope of the project. Each descending level represents an increasingly detailed definition of the project work"*. Interesting about

this definition is that it states that the WBS is deliverable-oriented, while previously in the literature Project Management Institute 2004 had defined it as activity-oriented (Norman, Brotherton, and Fried 2008). The change in definition, comes from the fact that a deliverable-oriented wording forces the creator of the WBS to state the deliverables in a clear manner. This turns the structure into a referencing point throughout the execution of the project. Therefore, it can also serve as a means to validate a project beforehand (Colenso 2000).

3.2.2 Decomposition method

In a WBS, level 1 is the highest level and represents the main deliverable(s) of the project (Colenso 2000). After identifying the main deliverables, the next step is to decompose these deliverables into logically distinct elements that can be clearly linked to the higher level ones. This step should be repeated until the desired level of detail has been reached. For a project, this particular level is dependent on risk, complexity, desired level of control (Colenso 2000) and effective communication (Norman, Brotherton, and Fried 2008). After reaching the desired level, the structure should be evaluated on opportunities to reduce the number of levels. Figure 4 shows an example of a WBS.

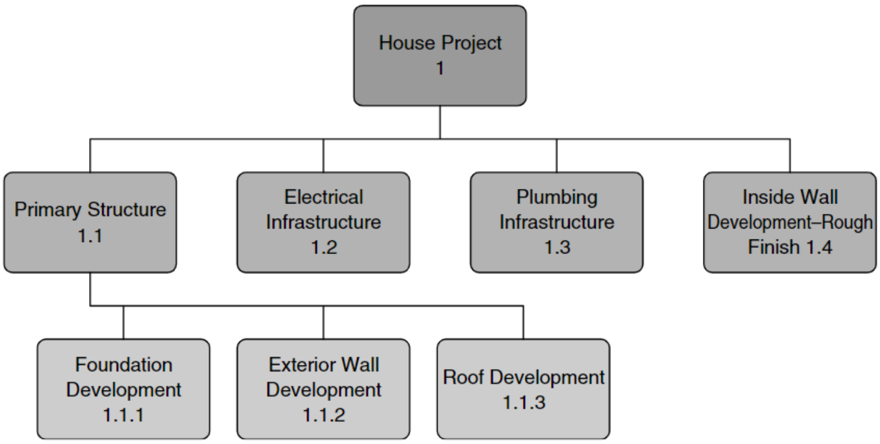


Figure 4: WBS example from Norman, Brotherton, and Fried 2008

In order to create a WBS it is important to break down the project properly. There are a few key principles described by Norman, Brotherton, and Fried 2008 that apply to the decomposition of the project into lower-order deliverables. First of all, every element (if decomposed) should be broken down into at least two child elements, otherwise the decomposition is unnecessary. In addition, accumulating all child elements from a specific parent should equal 100% of that parent element, also called the 100% rule (Haugan 2001). Next to this the WBS should demarcate the scope and should not consider any tasks that are considered out of scope. Finally, the elements present in the WBS should be described with nouns and adjectives rather than with verbs. There are several possibilities regarding the orientation of a WBS. Globerson 1994 states that the first level of a WBS refers to the project. However, the second level may refer to a geographical location, functions or components. The paper gives five clear examples of different orientations in decomposition structures. The examples given are from the service sector. However, Globerson 1994 claims that concepts used in in the service sector are also usable in an industrial environment. Figures 5, 6, 7, 8 and 9 show the different orientations of a WBS as presented in Globerson 1994.

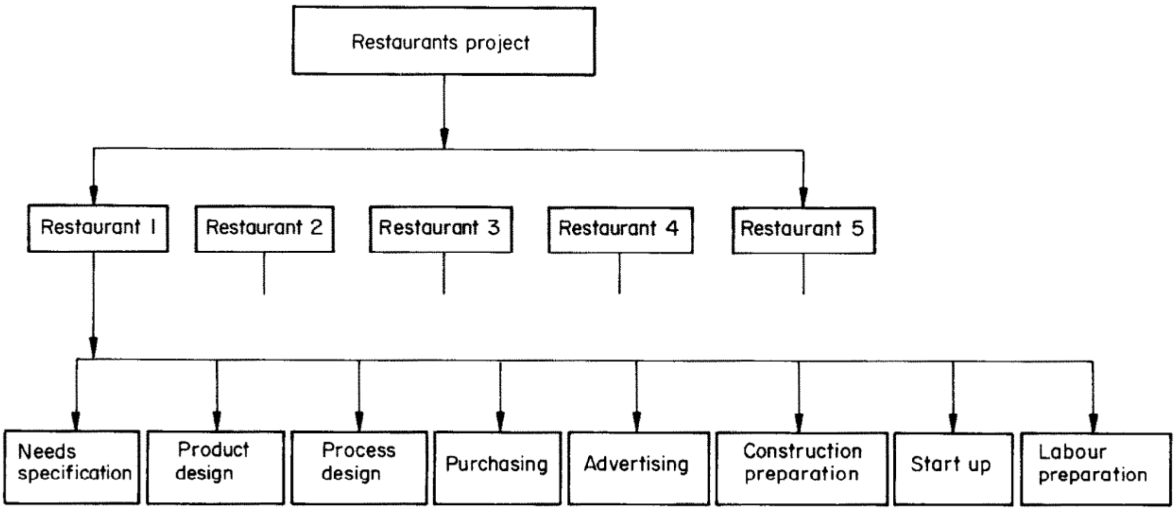


Figure 5: A WBS with a geographical orientation

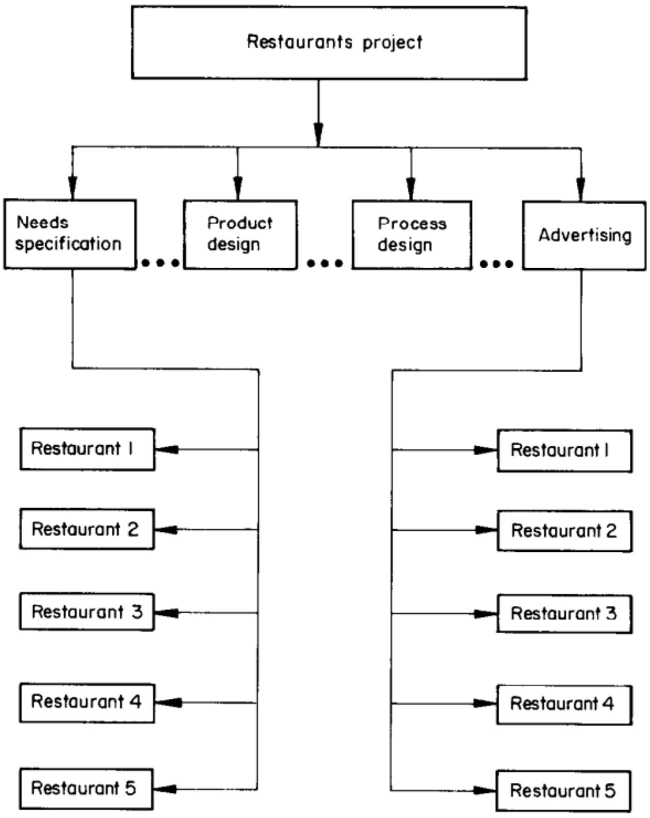


Figure 6: A WBS with a functional orientation

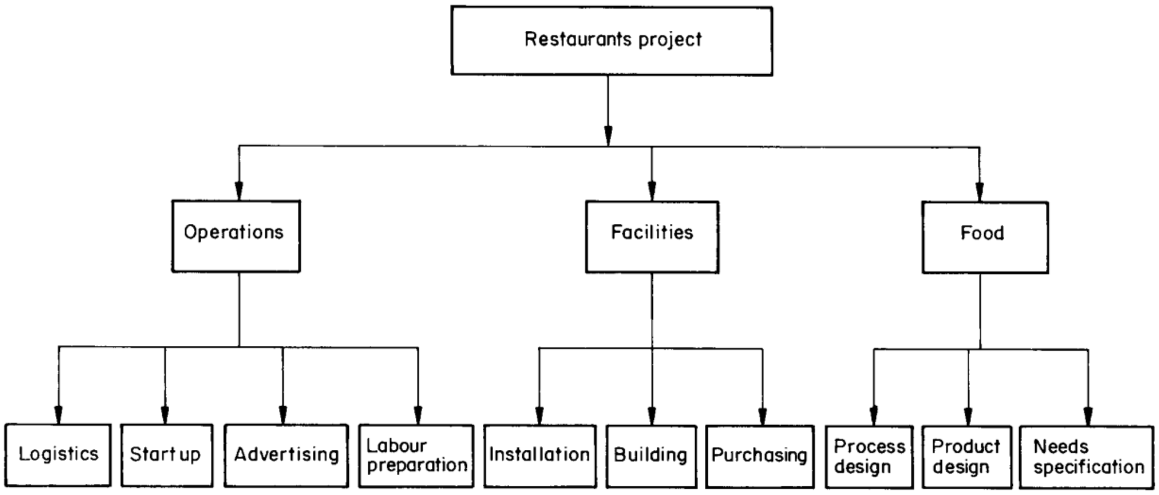


Figure 7: A WBS with a logistic orientation

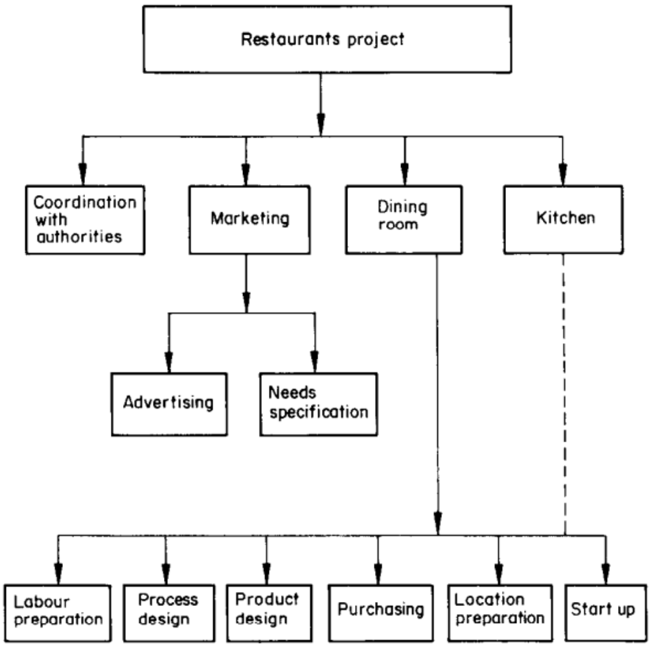


Figure 8: A WBS with a subsystem orientation

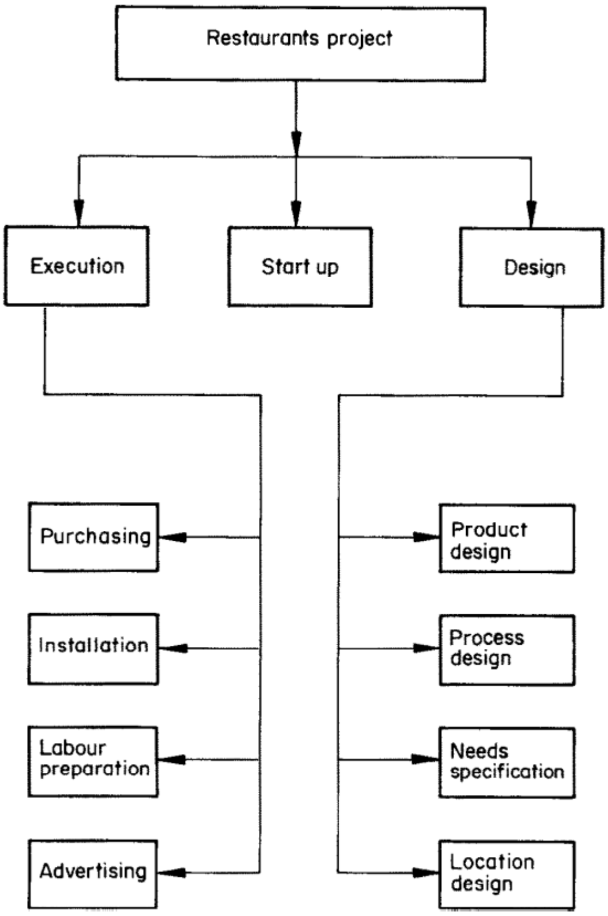


Figure 9: A WBS with a timing orientation

3.2.3 Work packages

Work packages are at the lowest level deliverable of the decomposition structure. Work packages include schedule activities and milestones required to finish it (Project Management Institute 2004). Work packages represent all tasks that need to be executed during the project. Their completion naturally transforms in finishing the higher-level WBS elements (Norman, Brotherton, and Fried 2008). Even though work packages are the lowest level of the WBS, a work package itself can still contain information on sub-activities, tasks or milestones for the delivery of the package. Activities included in a work package are interconnected and form a network with the activities of other work packages. Globerson 1994 states, that even if one organizational unit is responsible for certain activities in a work packages, they still might not have full control over these activities, since they are preceding from work packages they are not responsible for.

According to Norman, Brotherton, and Fried 2008, a qualitative WBS contains work packages that represent a discreet deliverable of the project in the form of a product, service, result or outcome. The work package identifies tasks, activities and milestones that are required to be completed in order to properly fulfill it.

Responsibilities for delivering the content of a work package should be assigned to a single organization or individual, in order to properly plan and execute a project, according to Globerson 1994. Regarding the size of a work package, Hughes 1986 states that there is an optimum size. The amount of management effort that is required as a function of detail has an inverse U shape. Meaning that a position should be found for which the level of detail is sufficient enough to carry out a work package, resulting in less managerial strain. Too many levels in the WBS generate too much information and complicate the management. Contrarily, having too few levels deteriorates the communication and coordination. Lavold 1997 claims that four to six levels are most suitable for large scale projects. Work packages should be made measurable in units, such as labour hours, budget, or weight (Hughes 1986). Norman, Brotherton, and Fried 2008 states that activity definition is the starting point of the development of a project schedule. This activity definition relies on a proper decomposition of this project. In other words, work packages from an accurate WBS can be used to define activities which then can be scheduled, producing relevant project tasks, activities and milestones. The work packages contain work that can be performed and tracked. When fully developed, they also enable the elaboration of cost estimation and the monitoring and controlling of the project.

3.2.4 Constrained Work Packages (CWP's)

Elaboration on the research of the scheduling property of work packages, has been done by Choo et al. 1998, who invoke the concept of Constrained Work Packages (CWP's). Together they developed a computer program that facilitates automated detailed scheduling of work packages in construction industry. This program also integrates construction data enabling it to visualize relationships between work packages. After defining the work packages, the research identifies various constraints for each work package. For example, the same resource cannot be assigned to 2 different work packages at the same time. Only when all constraints for a work package are satisfied, the work package can be executed. Data is added to the work packages resulting from the following topics of the constraints:

- *Contract*
- *Engineering*
- *Materials*
- *Labor and equipment*
- *Prerequisite work*

This extra information supports status reporting of the project through the collection of cost and time data. The system takes practical constraints into account that could block work packages from being executed when not all conditions necessary for execution are met. Providing each work package with information in the fields mentioned resulted in a network of relationships between work packages that can be utilized in automatic schedule development.

A proper definition is essential for both the practicability and the division of work packages (Ministry of Infrastructure and Environment 2013). The additional questions in the research of Choo et al. 1998 (shown in Appendix A) regarding the fields of constraints provide a good basis to sharpen the definition of work packages.

Other literature in this line of research is the study of Wang, Lin, and Zhang 2020. They tried to perform resource-constrained scheduling of construction projects with work package-based information modelling. The result is an information model, enabling a fluent data flow of scheduling and resource information coming from work packages. The model uses Building Information Modelling (BIM), precedence relation rules and databases to generate useful schedules. In order to make the program succeed, specific fields of information are added to their work packages. The data model provided in the research is shown in Figure 10.

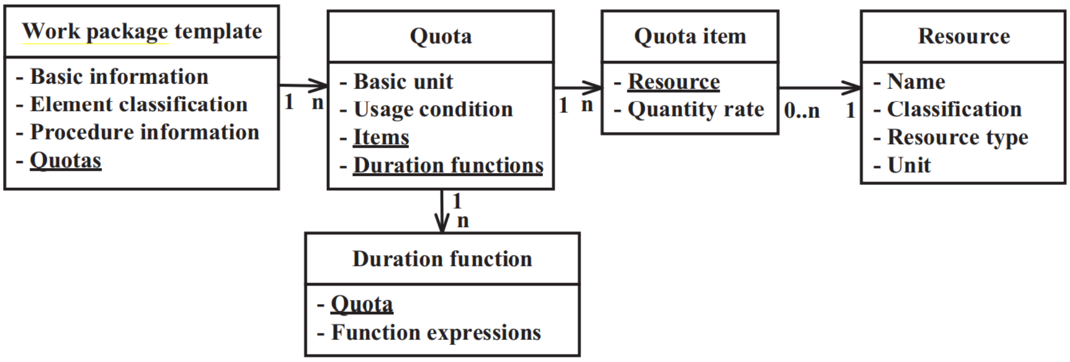


Figure 10: Work package data model, from Wang, Lin, and Zhang 2020

3.2.5 Validation

Colenso 2000 discusses that a WBS could be validated in two steps. The first step is validation through a bottom up approach. Starting at the work packages, applying the 100% rule to check whether all elements have been accounted for. In the second step the defined WBS deliverables should be compared to the defined project deliverables. This step serves as an evaluation to ensure that the WBS is properly scoped.

3.2.6 Attachments

A WBS mainly relies on two attachments that facilitate the development or support the execution of the concept. At the basis of a WBS lies the project scope statement (Norman, Brotherton, and Fried 2008). This document outlines the project and therefore plays an important role in the formulation of the deliverables employed in the WBS.

The other important attachment is the Resource Breakdown Structure (RBS). This concept encompasses the process of charting the subcontractors (Norman, Brotherton, and Fried 2008). An RBS helps define work packages, since individual responsibility is a criterion for the correctness of a work package. Not only does an RBS help define work packages, it also helps allocate them. For a proper division of labour it is essential to know what parties are involved and who will perform what tasks.

3.2.7 WBS dictionary

The WBS dictionary is an elaboration on the elements presented in the WBS. It defines deliverables more extensively and for all parties involved in the project. In addition, the dictionary contains information on what part of the project each work package is expected to address. It also serves as a last resort for questions regarding the scope when those questions are too detailed to be able to deduce them from the WBS according to Norman, Brotherton, and Fried 2008.

Latief et al. 2019 states that the WBS dictionary also needs to contain information about the resource(s) necessary for the completion of a work package. In addition, it should state the particular method that needs to be applied to complete the task.
Project Management Institute 2004 adds that information on responsibility, cost estimates, quality requirements and acceptance criteria also need to be stated in the WBS dictionary. Which makes it an indispensable document for the management of a project.
This dictionary is an amplification of the WBS and can therefore only be created after the WBS has been created (Norman, Brotherton, and Fried 2008).

3.3 KPI's for performance measurement

Next to a final assessment of a the generated solution, the impact of the solution must be made quantifiable after implementation. This measurement will serve as validation of the added value of the solution. For this measurement a norm and reality have to be established. The norm and reality here are represented by Key Performance Indicators (KPI's). These KPI's quantify the impact of the solution and ensure the ability of validation of the solution.

Since the company is in need of a suitable method for planning and control, the KPI's selected result from a literature study on those two aspects. Planning and control methods impact the overall performance of project management and support the generation of an early schedule. Therefore, KPI's for performance measurement of project management and planning have been identified.

Blomquist, Farashah, and Thomas 2016 state that both project planning and project management heavily influence the overall success of the project. Therefore, finding project success factors give a good indication of the effectiveness of an implemented solution for planning and control.

Albert P.C. Chan and Ada P.L. Chan 2004 establish multiple KPI's for the measurement of project success in the construction industry. They conclude that performance of a construction project is mainly characterized by the indicators: cost, time and quality. From this research the following KPI's are adopted:

- $\textit{Speed of construction} = \frac{\textit{Gross floor area } (m^2)}{\textit{Construction time (days or weeks)}}$
- $\textit{Unit cost} = \frac{\textit{Final contract sum}}{\textit{Gross floor area } (m^2)}$
- $\textit{Time variation} = \frac{\textit{Construction time - Revised contract period}}{\textit{Revised contract period}} \times 100\%$
  (where: revised contract period = Original contract period + EOT (Extention Of Time, that has been granted by the client)

Because of the nature of the Trento Construction process, projects are relatively similar. Even though cost and speed might be negatively influenced by the number of levels that will be constructed in a project, Trento Construction projects involve a standard number of floors. Therefore, these first two KPI's will give a proper indication on the project performance and thus the project management. The third, time-bound, indicator covers the measurement of the accuracy of the project planning, so that both the planning and control aspect of a new method can be made quantifiable and a positive impact of a solution can be verified.

3.4 Conclusion

Nijhuis Bouw wants a method that could support automated schedule development and could help them track the progress of construction projects. Literature suggests that a product-oriented WBS with a deliverable-oriented formulation, is a suitable method for scheduling and control for the company. Hence, it is selected in this research. Furthermore, knowing that Nijhuis also wants to be able to check progress of construction projects, the possibility of a progress view based on the functional-orientation will be added to the research. It could be seen as a view of the progress per project phase. This way the company could check the progress of a project, using a completion percentage per phase based on all to-be constructed houses involved.

The make-to-order nature of the Trento construction method makes it compatible with a decomposition structure like the WBS. Most of the projects could be supported by an accurate decomposition, because of similarity in the process.

The literature states that, one of the attachments of the method, the project scope statement is indispensable when adopting the WBS method. The elements placed in the decomposition should be clearly defined and there is no room for ambiguity. Looking from the company's perspective, this is not a problem. Nijhuis has already completed multiple construction projects by this method, that has a repetitive nature. Therefore, the project scope statement could be easily determined by the company.

In addition, the literature suggests that an RBS for each project should be created. This attachment gives an oversight of all parties involved in the project. In Nijhuis's case the RBS consists of their co-makers, who are involved in most of their projects.

Work packages take a prominent role in this research as project scheduling and project control heavily depend on them. In this literature review it came forward that work package definition, in terms of content, is indispensable when using work packages for these two purposes.

Work packages should be assigned to a single organizational unit or individual and should be made measurable in terms of labour hours, budget or weight for instance, according to the literature. Defining the content of a work package can be done on different aspects. In this research we will adopt the constraints presented by Choo et al. 1998, as input for the definition of a work package. These aspects are revisited in chapter 5, to identify essential data streams.

Finally, the literature confirms the potential of CWP's regarding automatic scheduling and checking a projects progress. Automatic schedule generation is done by setting up several fields of constraints for the work packages and make a work package available for execution when those constraints are met. This principle is demonstrated using a process model in chapter 4. Checking the projects progress is done by verifying if a clearly defined work package has been completed. A data model facilitates this scoping process of a work package. This is discussed in chapter 5.

4 A Process Model

Now that we have selected WBS as a suitable method for planning and control for Nijhuis Bouw, studied the literature about this concept and put its elements into the perspective of the company, the next step is to get more insight into the Trento Construction process. We do this to examine the compatibility of the Trento construction process with the WBS method. In addition, we need to investigate the possibilities for Nijhuis to automate schedule generation using WBS. A way to provide insight and support adaption to change of processes, is process modelling (Aldin and De Cesare 2009). Therefore, we will construct a process model. In addition we will dive deeper into a part of that model on a work package level, in an attempt to illustrate a constrained work package and its conditions.

4.1 Purpose of a process model

Without creating a process model, the WBS is merely a breakdown of the whole process. This is already helpful when creating a planning. However, next to an understanding of the steps involved in a construction project, insight into the chronological order and relationships between the activities contribute to the development of a WBS that is more suitable for scheduling purposes. Dependent on the type and the quantity of the houses, all work packages necessary to build a specific house could be listed. In order to go one step further and enable a system to schedule these listed packages we need a network of dependencies that facilitate scheduling rules. In this thesis we will refer to this as Constrained Work Packages (CWP's), a term also used in the work of Choo et al. 1998. CWP's are work packages that include defined conditions. These originate from the execution of previous work packages that are related to the current package.

4.2 Process modelling methods

Business process modelling facilitates a common understanding and analysis of the process (Aguilar-Savén 2004). Processes can be modelled in various ways. In order to find out what method we need to use for this research, we need to conduct the scientific literature on modelling methods.

Aguilar-Savén 2004 and Aldin and De Cesare 2009 review various methods for process modelling. Before we are going to review all methods, we will first establish the requirements our modelling language needs to meet. This way, we can eliminate irrelevant methods and assess the relevant modelling methods more thoroughly.

The model we are going to create is based on a construction process. For this process to be presented correctly a modelling language that enables us to clearly address process activities, is necessary. Some modelling techniques are more oriented towards depicting data streams and data architecture, topics that are more relevant for 5. The Trento construction process consists of several phases, so in addition the modelling method needs to support categorization of activities. Also, the model needs to display relationships between and conditions for activities. This way a correct chronological order of the process can be established, which is essential for Nijhuis if they want to let the WBS support the scheduling process. As a last requirement, the model has to be clear and comprehensible.

This brings us to the following list of criteria we will use to reduce the amount of options for a process modelling method:

- *Address process activities*
- *Address process phases*
- *Display relationships*
- *Display conditions*

After assessing the methods mentioned in the Aguilar-Savén 2004 and Aldin and De Cesare 2009, we eliminated the methods that are not relevant for the purpose of solely modelling the activities involved process instead of data architecture for instance. This leaves us with a selection of modelling languages that will be evaluated below.

4.2.1 Flow chart technique

The flow chart technique is a simple technique with limited symbols. Due to its simplicity it can be easily red and understood (Aldin and De Cesare 2009). The method is used to visually represent a program logic sequence, work or manufacturing processes or organisational structures (Aguilar-Savén 2004). The flowchart method is characterized by its flexibility, one of its stregths. The language has many degrees of freedom, which makes it a useful method for modelling large and complex processes. In addition, due to its limited symbols and its user-friendliness, the flow chart technique excels at communication. The method supports quick development of a preliminary version of the process model when using an agile approach. Therefore, a flow chart is a good tool to identify bottlenecks or inefficiencies. Figure 11 shows a simple example of a flow chart from Aguilar-Savén 2004.

Flexibility is also a drawback of the flow chart technique. Too much flexibility often results in large models (Aguilar-Savén 2004). Additionally, the boundary of the process may not be clear. The method also does not include an option to distinct main and sub-activities. This makes it more difficult to read the chart in terms of identifying its primary flow. At last, the modelling technique does not make use of sub-layers. This makes it hard to navigate through the model and makes it hard to connect organisational functions or departments to activities, which makes increases the risk of getting lost. Therefore, the flow chart technique performs best when used for processes that need a high level of detail and is not a good method for providing overview.

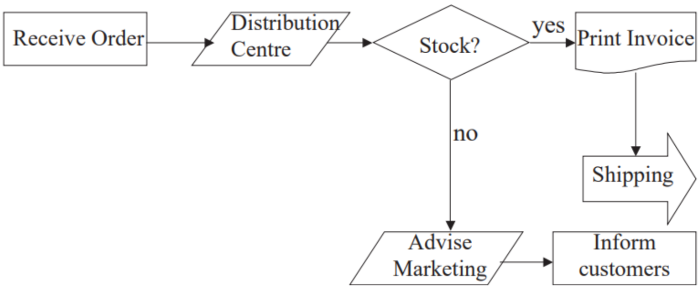


Figure 11: Flow chart example for Aguilar-Savén 2004

4.2.2 Petri nets

A Petri net is a graphical-oriented representation that uses an underlying mathematical basis (Vergidis, Tiwari, and Majeed 2008). It is used for system design, specification, simulation and verification (Aguilar-Savén 2004). Petri nets perform well at modelling processes that involve a number of communicating activities, like a control flow or business process. A Petri net consists of places, transitions and arcs. The arcs connect the places to the transitions or contrariwise. This way, tokens can flow through what is called the network. Figure 12 shows an example of the basic notation of a Petri net from Aldin and De Cesare 2009.

Petri nets consist of few different elements, which increases the understandability. The way in which a network is created makes it easy to understand the structure of the process (Aldin and De Cesare 2009). In addition Petri nets show how individual activities interact with each other. The underlying mathematical representation enables the model to be simulated. Petri nets allow for changes to the network, without losing the identity of the model.

Putting these Petri nets into practise comes with a few drawbacks. First, when adopting Petri nets, a proper data concept is essential. Otherwise the model with become excessively large. Second, due to the fact that there are no hierarchy concepts, it is not possible to create a model that consists of sub-models with well-defined interfaces (Aguilar-Savén 2004). Last, despite extensions to the method, it is still considered to be non user-oriented. Application to business process modelling requires a certain level of expertise, which makes it a difficult method to adopt (Aldin and De Cesare 2009).

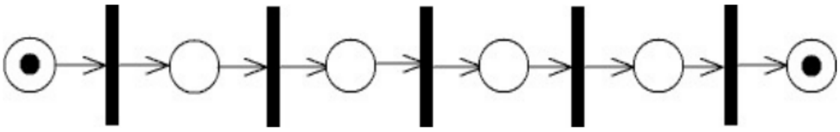


Figure 12: Basic Petri net

4.2.3 Business Process Model and Notation (BPMN)

Business Process Model and Notation (BPMN) is one of the most reknown process modelling techniques and was found to be the "de facto standard" by Kocbek et al. 2015 at the time. The ISO certified language facilitates robust communication between business and IT. It is a graphical notation developed to form a readily understandable standard in process modelling for all stakeholders. A business process model consists of events, activities, gateways and connections which are used to represent the process. In addition there are swim lanes, which are frames that can be used to categorize the process. Figure 13 shows an example of a simple BPMN from Aldin and De Cesare 2009.

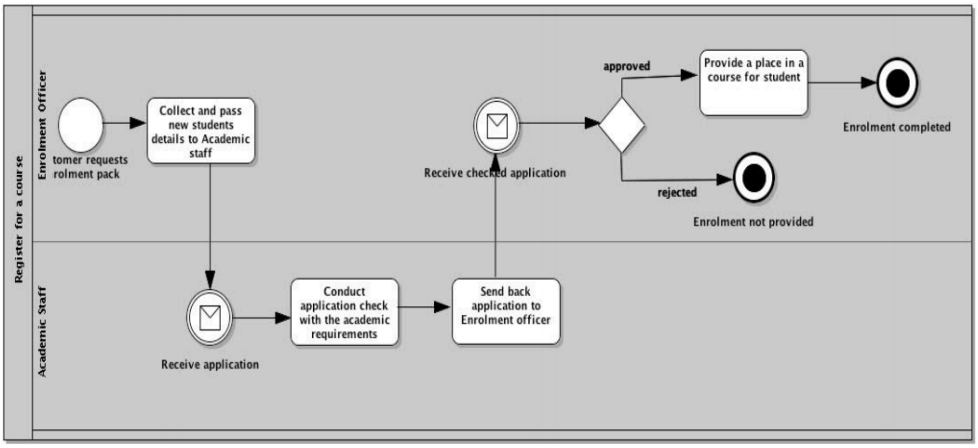


Figure 13: Basic BPMN example from Aldin and De Cesare 2009

BPMN is suitable for the creation of extended models as well as their decomposition (Aldin and De Cesare 2009). In addition the method has a high flexibility, meaning changes can be made easily without influencing the nature of the model. It is easy to use and understandable for both business and technology users. BPMN has a high expressiveness, meaning the method is suitable for a lot of different modelling challenges (Kocbek et al. 2015).

A drawback of the method is that it includes a specialised notation (Aldin and De Cesare 2009). This, in combination with the large variety of constructs (Kocbek et al. 2015), can make BPMN a complex notation. However, it is not necessary to use this specialised notation. Therefore, it still remains a suitable options when different stakeholders are involved.

4.3 Modelling method selection

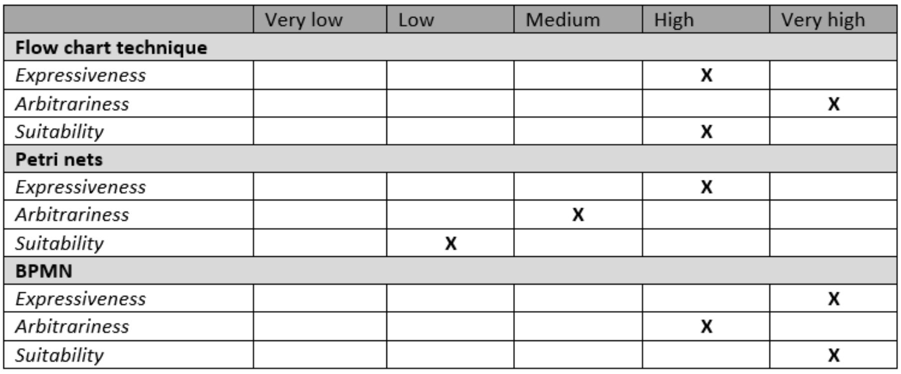
Falkenberg 1996 establishes three quality relevant characteristics of modelling languages that can be used to assess process modelling methods in order to find the most suitable one. We will adopt these properties and use them for method selection. For this selection process, the different characteristics count equally heavy and will be assessed using a 5-point Likert scale.

The properties and their definitions mentioned by Falkenberg 1996 are:

- Expressiveness: *concerns the degree to which a modelling language is capable of denoting the models of any size and any kind of application domain.*

- Arbitrariness: *represents the degrees of freedom one has when modelling a certain application domain. A liberal modelling language results in multiple ways to model the same process, while a modelling language with a low arbitrariness only allows a few or even one possibility.*
- Suitability: *property representing the degree of applicability of the modelling language or the degree to which a language could be tailored to model a certain application domain.*

Using the Likert scale, the different process modelling methods are evaluated on these properties. After conducting the literature study, the following scores have been given:



	Very low	Low	Medium	High	Very high
Flow chart technique					
Expressiveness				**X**	
Arbitrariness					**X**
Suitability				**X**	
Petri nets					
Expressiveness				**X**	
Arbitrariness			**X**		
Suitability		**X**			
BPMN					
Expressiveness					**X**
Arbitrariness				**X**	
Suitability					**X**

Figure 14: Process modelling methods selection table

Figure 14 shows that the Petri nets score the worst. The mathematical model behind a Petri network demands for data that is not readily available at Nijhuis and therefore makes the modelling method unsuitable. This leaves us with the flow chart technique and the BPMN. Two fairly similar techniques, however the slight differences between these methods make the BPMN seem to be a better fit. It has the advantage that it is able to deal with large models and additionally the so called swim lanes are a clear way of representing phases in the construction process. Therefore, the Business Process Model and Notation is the selected process modelling method.

4.4 Process model creation

Now that a suitable method for the creation of a process model for the Trento construction process has been selected, it is time to critically analyse the current process. In this subsection, we analyse both the theoretical and the practical perspective of the Trento process in order to validate the accuracy of the existing Trento Concept.

4.4.1 Creation approach

The current Trento Construction process is already focused on the reduction of stochasticity by using a make-to-order process. In addition, sub-contractors are a limited number of companies with whom Nijhuis maintains a good relationship. This results in companies getting used to each others processes, increasing the efficiency and developing a willingness to assist each other when problems occur during a project. Next to this, the Trento process is supported by a process outline, called the Trento Concept. This outline has been created by the construction process developers of Nijhuis in cooperation with other employees.

One could look at this outline as a template that typifies the Trento construction process. Application of this template should guide project planners in their job of making a schedule. This outline could provide a great basis for the creation of our process model using the BPMN. However, the construction industry is a sector where theory and practise are likely to deviate influenced by numerous unpredictable factors. Therefore, we first need to investigate if the outline represents the reality accurate enough before we can use it.

4.4.2 Trento Concept validation approach

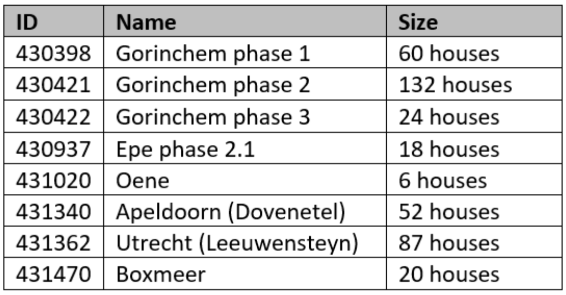
For the validation of the outline we need to take a critical look at project schedules. This way we can compare the theory to the reality. Nijhuis uses a tool called KYP, for project schedules. This tool gives a clear oversight in what tasks have to be done when and by whom. In order to validate the template, we will compare it with three KYP-schedules.

To find useful schedules that could be compared with the template, we need to set up criteria. The first one is that the houses should be rental houses. When a Trento construction project is going to take place, the difference between rental houses and owner-occupied houses is that buyers can add features like a dormer. This disturbs the generic nature of the process and is less convenient for researching purposes. The features of rental houses are agreed upon with the client and are the same for every house in most cases. The second criterion is that the houses that are planned to be built in the project need to be ground-floor houses. Multi-story building projects involve a more complicated process and are bound to more safety regulations making it unsuitable to compare it to the template.

We want to be sure that the schedules used for comparison, are representation of the real situation. Therefore the schedules have to be from projects that have already been completed. In addition, we want the completed projects to be comparable in size in order to be able to draw a conclusion on the accuracy of the template. Finally, this yields the following list of criteria for the projects to be compared:

- the project involves only rental houses
- the project involves only ground-floor houses
- the project has already been completed
- the projects are of approximately the same size

Therefore, after filtering Nijhuis's projects on our criteria, we finally need to make a decision on the project size for which we want to investigate the template's accuracy. In consultation with planners at Nijhuis, the following list of projects that meet the requirements remained:



ID	Name	Size
430398	Gorinchem phase 1	60 houses
430421	Gorinchem phase 2	132 houses
430422	Gorinchem phase 3	24 houses
430937	Epe phase 2.1	18 houses
431020	Oene	6 houses
431340	Apeldoorn (Dovenetel)	52 houses
431362	Utrecht (Leeuwensteyn)	87 houses
431470	Boxmeer	20 houses

Figure 15: List of projects

Looking at the range of the different project sizes an average cluster of three would be: 'Gorichem phase 1', 'Apeldoorn (Dovenetel)' and 'Utrecht (Leeuwensteyn)'. The size of the projects being about average has the advantage of being roughly representative for the whole range. However, difficulties with the data storage of completed schedules in KYP unfortunately denied access to two of these three projects. Therefore, a different cluster had to be made. This cluster consists of: 'Gorinchem phase 3', 'Boxmeer' and 'Apeldoorn (Dovenetel)'. Again, looking at the size, these projects formed the cluster that was second closest to the average project size.

4.4.3 Trento Concept validation

The Trento Concept consists of 4 phases: site preparation, hull, exterior wall and dismantlement. Phase one and two run sequentially and phase three and four run simultaneously. Except for the first phase, these phases are divided into what we will call chapters. These chapters contain numerous detailed tasks. All tasks in a chapter combined, equal the work that needs to be done to complete the chapter they are in.

In order to compare these projects, the concept version's phases and chapters are listed in an Excel sheet. Hereafter, the KYP-schedules of the three selected projects have been studied and their chapters are listed in the sheet as well. This sheet can be found in Appendix B. Colours indicate which phase the chapter takes part in, to be able to quickly see the similarities in the projects and the amount of different steps involved in the phases.

The comparison of the schedules (Appendix B) shows that the template provides guidance for the planners of Nijhuis, because two out of the three schedules are almost identical to the Trento concept version. One of those two schedules misses only a few chapters that might have not been relevant in that projects and the order of the chapters used from the template are rarely swapped (less than 10%, based on the number of chapters that have a different order with respect to the Trento concept, divided by the total number of chapters).

The third schedule is about half the size of the concept which seems to be in contradiction with the other two. However, when looking at the chapter titles, every title used in the schedule could be found in the concept version as well. This still supports the accuracy of the concept version, since the steps necessary to complete the project were all drawn up from the template.

From this, we conclude that the concept version of the Trento Construction process for the creation of a process model is justifiable. Validation shows that the complete concept or (specific parts of it) is a good representation of the reality. Specific chapters involved in the a construction project are drawn up from this template.

4.4.4 Process model design

After selecting the process modelling technique, formulating an approach and validating the Trento Concept; the model is constructed. It can be found in Appendix C. The model represents the whole process on the level of the chapters from the Trento Concept. It serves as a means to gain oversight.

As mentioned before, the process consists of four sequential phases of which the last two run simultaneously. The swim lanes from the BPMN indicate these phases. The model starts after the acquisition of permits and the approval of the project, when the preparations of the construction site start. The timeline of the model goes from left to right. However, new phases start at the left hand side of the model to keep it compact.

The model shows that at some point, a decision has to be made regarding the utility company. These companies are an independent third party. They do not rely on Nijhuis's project and are therefore an unpredictable organization. Hence, there are two options in the process to schedule the utility company. When the utility company gets scheduled for option two, the final groundwork of the exterior wall phase have to wait until the utility activities have been completed.

4.5 Model details

4.5.1 Constraints, conditions and relationships

Before further elaboration on the model, it is important that we clearly explain what we mean by the terms: constraints, conditions and relationships. This avoids ambiguity when we use them in relation to the process model and the zoomed-in version. The terms constraint and condition are used interchangeably, but the term relationship means something else in this context. We will explain this using a simple example from the model.

In the "Dismantlement" swim lane is slots and screed. This chapter contains the activities necessary to protect cutouts adjacent to the side of the floor and thereafter pour the screed. The floor remains wet for a certain time and no tasks can be performed on both floors of the house. A condition, and thus a constraint, for the screed to be poured is that the floor has been swept and cleaned up. Next to conditions for the start of activities in this chapter, it also brings along conditions or constraints for the activities following. Namely, the activity either has to not take place at one of the floors where screed has been poured, or has to be scheduled the correct time frame subsequent to pouring the screed if it does take place at one of these floors.

In the current model, these constraints remain invisible. However, by zooming in on the model, we can try to visualize them. Later in this section the purpose of this approach is explained in section 4.5.2.

After pouring the screed, the chapter "Aanhelen casco en binnenwanden" starts. Concerning the process model, this is what is meant by a relationship. A relationship between activities is the order in which activities take place. This order is formed by the constraints carried by activities. Regarding this example; sweeping the floor is a constraint of pouring screed. Therefore the activity of pouring screed forces that the floor is swept before the screed is poured. The relationship between the activities is indicated by the arrows connecting the boxes.

4.5.2 Zooming in on the model

At this point the model gives a rather basic but clear overview of the process. We have created this overview to get an idea of what the process looks like, after which we can zoom into a specific part of it. We want to zoom in to establish constraints and relationships between activities on a higher level of detail. Establishing constraints and relationships for the full Trento process is a complex task and takes time. Due to our time frame we therefore cannot perform it on the whole model.

To explain why we want to increase the level of detail, we need to take a look at 2.5 again. This part describes the steps that will be taken in this research to reach the goal set, which is shaping a method for planning and control to the needs of the company. As we have seen in the literature study performed in chapter 3, splitting up the process in smaller tasks will finally result in work packages. These work packages are a key concept in the WBS theory and are also of great importance when it comes to ERP design in Nijhuis's case.

In order to realize their vision of shifting towards a make-to-order strategy, Nijhuis might want to adopt the selected planning and control method by developing CWP's. In theory, after both Nijhuis and their client have agreed upon a project, work packages could be automatically generated based on the house type and quantity. The sum of these work packages equals the total project. Without a time component, these work packages are merely a division of the workload. It is the combination of well-defined work packages and identification of conditions and relationships, like time restriction, limited space or other precedence relations between these packages that has the potential of a solution that Nijhuis is looking for.

The model in Figure Appendix C needs a more in depth view. At this moment it is too superficial, however when zooming in; we can reach the level of detail that equals the level necessary for defining work packages. By doing this, we can investigate the value of researching conditions and relationships between activities on a work package-level and propose a solution that involves the application of a WBS with CWP's that could be scheduled based on the position of related packages.

4.5.3 Process interval selection

As mentioned, zooming in on the entire Trento process takes a lot of time. One has to be familiarized with the tasks involved on a level that requires a lot of knowledge about the construction industry. In addition, we are trying to provide a prove of concept on constrained work packages, which means that we will try to verify whether the principle could provide a suitable solution for Nijhuis. Therefore, we need to make a decision on what part of the Trento process we want to model in depth.

For this decision the complexity of the steps involved are taken into account. Complexity of the activity is considered, because in principle, a less complex activity requires less construction knowledge. For this research it is more convenient to come up with a simple yet accurate model to try and investigate the functioning of WBS with CWP's for Nijhuis than to focus on developing an intricate model, because the goal is to prove a principle. Activities involving complex steps also provoke complex conditions, which could draw the focus from investigating the principle to creating a time-consuming model.

After establishing these decision criteria, slots and screed has been selected to model in depth in consultation with a planner of the Trento team. This interval of the process model will be investigated on a detailed level. Section 4.5.4 will describe how we will do this.

4.5.4 Process interval analysis

In cooperation with a planner of the Trento team, this interval of the construction process has been analysed. After an analysis of the activity involved and the conditions necessary to complete this activity, the in depth process model is created. The simplified model is shown in 16 and the extended model can be found in Appendix D. The Figure displays two types of tasks that carry constraints, marked by the yellow and blue section. In the yellow section are tasks impacting the hollow-core slab floor and in the blue section are tasks around this supporting floor. The Figure indicates the order in which the activities need to be carried out. For some of these activities the order does not matter. These activities are placed at the same spot of the timeline at the bottom.

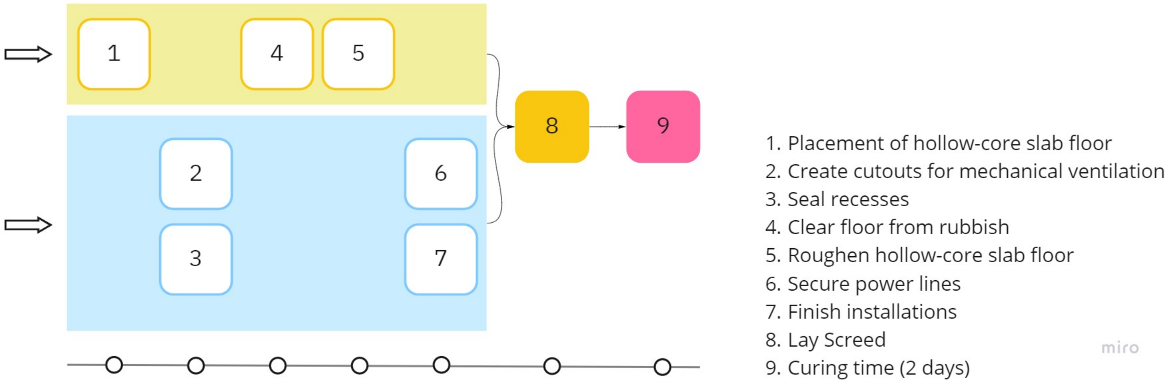


Figure 16: An in depth model of a part of the Trento Concept using the BPMN method (simplified)

The focus in this model is on laying screed. A screed is an extra floor layer that is poured over the supporting floor. This extra layer provides an even surface that enables the placement of vinyl floors for instance. It also serves as both heat insulation and soundproofing. The supporting floor is a hollow-core slab floor, a fundamental concrete floor element with a hollow centre that is used for the piping system.

All the activities presented in the Figure evoke individual constraints. For instance, if sealing the recesses is not performed before the screed is laid, screed that is poured on the supporting floor will flow out through the seams of floor element. Hence, sealing recesses is a constraint for the work package "Lay screed".

The steps in the process described in Figure 16 are explained as follows:

- *Placement of hollow-core slab floor*: the most obvious constraint for laying the screed is that the hollow-core slab floor on which the screed is poured, has to be placed. The other activities as well as the main activity all take place on and around this element.
- *Create cutouts for mechanical ventilation*: examples for mechanical ventilation are the extractor hood in the kitchen or extractor in the bathroom. To be able to extract this air from the building, ventilation shafts that transport the air need to be placed through supporting floors. Hence, cutouts need to be made in the slab floor.
- *Seal recesses*: the screed is liquid. Therefore, all recesses have to be sealed. If this is not done before pouring the screed. The liquid will flow out through the seams between the floor

element and the walls. A consequence of not sealing the recesses could be that your crawl space will slowly fill up.

- *Clear floor from rubbish*: after the tasks mentioned above, the floor can be dirty. This could either be from the dust of creating the cutouts, but it could also be garbage of construction workers. The next step in the process is to roughen the floor element. After this step the floor is not to be cleaned. It is therefore important to clean the floor a bit beforehand, using a broom or simply by picking up the garbage by hand. The roughening of the floor cannot start when the floor is not cleared from rubbish.

- *Roughen hollow core slab floor*: roughening the floor enhances the attachment of the screed to the hollow-core slab floor. As a consequence, heat insulation and soundproofing also improve. In addition, a good attachment of the floor layers reduce the risk of crack formation in the screed floor. Cracks in the screed floor can inflict damage to the final floor layer, like a vinyl floor, at a later stage. Restoration is expensive and time-consuming.

- *Secure power lines*: power lines provide electricity to the building. They are on the supporting floor before the screed is poured over. To refrain the lines from floating in the liquid, the lines have to be secured. This ensures the quality of the top of the screed floor.

- *Finish installations*: a building contains multiple installations like an installation for underfloor heating. This installation lets warm water flow through tubes that are placed on top of the floor element. Screed is poured over the floor element and its level rises over the height of the tubes. Therefore, the tubes are also secured secured. When the screed floor is finished the place of both the underfloor heating distributor and the tubes cannot be adjusted anymore. Hence, installations have to be finished before the laying the screed.

- *Lay screed*: liquid screed is poured on top of the hollow-core slab floor until it has reached level at which it covers underlying installations and power lines.

- *Curing time (2 days)*: after laying the screed it has to harden for 2 days. After these two day, tasks that take place on the screed can be started.This consequence serves as input for other CWP's that take place on a screed floor.

After the main activity of the model in Figure 16 there is 1 constraint left. This is not necessarily a constraint for the main activity, but is put in the model to illustrate the fact that certain constrained tasks evoke new constraints once they are finished. In this case the curing time resulting from laying a screed, refrains other tasks from taking place on this screed for the next 2 days.

With sufficient knowledge of construction and the Trento process the analysis, like the one on the interval in Figure 16, could be repeated for the full process. This results in a network of activities and interdependence based on constraints.

4.6 Conclusion

Without insight in constraints among activities and a chronological order in which activities should be completed, a WBS is incomplete for scheduling purposes. To be able to adopt a system that could create schedules autonomously, we need to go a step further than work packages from a WBS. Work packages should contain information regarding precedence relationships and constraints and a work package must be available for execution when all conditions are met.

By comparing the schedule of three construction projects with the Trento concept schedule, we established that the concept matches reality. Trento construction process is a more standardized construction process. A model of the Trento construction process, that addresses activities and phases and displays relationships and conditions, is constructed using the BPMN method. When examine a part of this process on a work package level we find certain conditions have to be met before a work package can be executed. We also establish that a work package can evoke a constraint for other work packages.

The Trento Construction process can be seen as a network of work packages that are interdependent. Consequences of a certain work package can refrain another work package or multiple other work packages from execution. Therefore, we can say that the Trento construction process consists of a network of constrained work packages. Hence, the use of CWP's is a possible solution for Nijhuis.

5 A Data Model for Work Packages

After we identified WBS as a suitable method for planning and control for Nijhuis, we learned about its elements and how to put these into their perspective. Next, we focused on the planning part of the capabilities of this method. In chapter 4, we established that in order to take scheduling a step further along the line of Nijhuis's vision of automating construction processes, and thus generating schedules automatically, creating CWP's is a potential outcome and is also supported by WBS. In this chapter we again take a closer look at work packages, but this time we will focus on the control part of the WBS concept. Therefore, we will view the work packages from a data perspective and we will try to construct a data model for work packages.

5.1 Importance of a data model

The control aspect is an advantage of the WBS concept. Work packages can be smoothly monitored once the project is properly scoped and the activities to develop the deliverables have been divided into work packages. Work packages should contain several critical pieces of information, under which: a clear description of the task, the duration, the subcontractor responsible, a start and end date and guidelines regarding quality control. Once the tasks from the work package description have been executed, the work package has been completed. Quality control guidelines can now verify whether the package has been completed properly and if it can be checked off. At a construction site this verification is done by main contractors. Their job is to manage the project on an on-site level, in close relation with the subcontractors executing their tasks. This process of constantly verifying makes that the WBS concept has a positive influence on controlling projects.

Currently, monitoring of the construction project is done mainly based on experience of the main contractor. The main contractor leads the project, knows what tasks need to be done and checks them off. Employees from Nijhuis that are not physically present at the construction site, but want to know its current status, need to contact the main contractor. This procedure takes time and conflicts with the transparency within the company. We want to know whether monitoring work packages digitally could solve this problem. Integrating the WBS concept into the new ERP system by adding a list of work packages that can be checked off, would improve Nijhuis's overall transparency with respect to their projects. In addition, the implementation of such a function also seems interesting for project management purposes.

5.2 Requirements for the data model

In order to successfully implement a feature that could facilitate Nijhuis's desire of having a list with work packages that indicates a project's progress, the company needs a reliable data model. This data model will play a key role in the implementation of this list feature, since it is responsible for the connection between the available data and the user. It also functions as a means to visualize the essential data fields prior to the actual implementation.

In addition, the internal structure of Nijhuis has to be reviewed in order to identify important stakeholders and their desires. Nijhuis is a large company with several departments who all have different interests. These interests come with a variation of priority for certain types of data. Employees labeled as stakeholder will be discussed later on in this thesis.

Before we develop a data model for work packages, we first need to establish the company's requirements. The following requirements came forward in consultation with the company:

1. The data model needs to be a template that is usable for every work package
2. The data model needs to make sure that it makes work packages workable for every stakeholder
3. The data model needs to make sure that work packages are readily comprehensible and should only contain the essential information

Nijhuis values unity in the function and therefore wishes that all the work packages have the same lay out. Not every field of the template has to be filled. Only the fields necessary for the stakeholder executing the package have to be. This blue print aspect of the lay out of work packages makes it easier for employees to get used to a certain format and makes the work packages more pleasant to work with.

In addition the data model needs to make sure that the work packages are workable for every stakeholder. This means that, no matter what ones job is within the company, one needs to be able to carry out a work package that is formulated according to the established data model. As mentioned, Nijhuis is a large company and construction projects involve many stakeholders demanding different information. In order to make work packages workable for all these stakeholders, the data model needs to ensure their demand of information is met.

While making sure the work packages are workable, the packages need to stay readily comprehensible. Making sure only essential information is being displayed is important. Otherwise, users of the system could get overloaded with information which makes the feature unpleasant to work with.

5.3 A data modelling method

We now know why Nijhuis needs a data model and what the requirements of this model should be. The next step is selecting a data modelling method that meets these requirements. We will do this by conducting a literature study on the topic.

Since its development in 1976 by Peter Chan, the Entity-Relationship Model is the most commonly used method for data modelling. Diagrams created using this method, known as Entity-Relationship Diagrams (ERD), form an abstract visualization of an information structure that could be implemented without considering its physical implementation. At the time, Entity-Relationship modelling was introduced as a tool for database design that adopts a more natural view using entities and relationships, while having most of the advantages of the previously developed methods (the network model, the relational model and the entity set model) Chen 1976. Entity-Relationship modelling consists of three elements. Entities refer to the objects represented in the diagram. An entity in an ERD actually represents an entity set. For example: the entity students represents the whole list of students instead of the name of just one student, which is an entity.

Entities are connected using relationships. Next to showing what entities are connected to each other, relationships also show the cardinality between two entities using a crow's foot notation. Cardinality is the ratio of the relationship. For instance, if a company can only accept one project at a time, the ration company:project is one-to-one. There are different options for the cardinality, namely: one-to-one, one-to-many and many-to-many. In addition to these three possibilities between two entities, the cardinality at an entity itself can also vary between zero-to-one, zero-to-many and one-to-many.

Figure 17 displays different cardinalities using the crow's foot notation. The relationships displayed are: one-to-one, one-to-zero-or-one, one-to-one-or-many and one-or-many-to-zero-or-many. An example for a one-to-one-or-many relationship could be: one construction project involves one or many subcontractors. The amount of subcontractors cannot be zero, otherwise the project cannot be carried out.

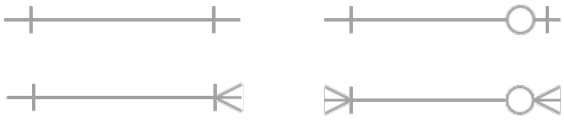


Figure 17: Various relationships in ER diagramming using a crow's foot notation

Entity relationship diagramming is a commonly used technique for data modelling. In addition, it is well-supported by various tools. Hence we will adopt this method in this thesis.

There are roughly three levels in data modelling:

- Conceptual modelling
- Logical modelling
- Physical modelling

Conceptual modelling, is the simplification of a system (Bézivin and Gerbé 2001) and is the starting level of data modelling. It is used to quickly develop a model that is accurate enough to discuss it, supporting agile development. In entity relationship modelling, conceptual modelling limits to the representation of entities and relationships. It forms a foundation for more detailed data models.

Logical modelling contains attributes and their classification. Attributes are also referred to as keys. Logical modelling elaborates on the conceptual model by identifying the minimum amount of essential data fields that have to be recorded in database architecture.

Physical modelling adds a more practical viewpoint to the previous levels. In physical modelled entity relationship diagrams, names of entities and attributes are in a database-compatible form. In addition, the names feature the data type in which it will be represented in the final database.

For the development of our data model, we go through each level of data modelling in this order. In the first level we identify the stakeholders. We do this using a stakeholder analysis. Then, we add entities to a conceptual model. After developing a conceptual model, we add attributes to the entities and decide on their classification in terms of keys. Finally we alter the model with respect to the physical modelling characteristics.

5.4 Input for the data model

Now that we have decided on a modelling method and proposed the approach, we need to gather input for the data model. The data model represents the data fields that are essential for a proper implementation regarding all stakeholders. Therefore, important data fields must be identified that can facilitate the work packages. For this reason we will revisit the requirements for the data model of a work package mentioned in section 5.2. All decisions made regarding the development of the model are evaluated on these three aspects.

Essential data fields are extracted the following sources: scientific literature, construction project schedules in KYP and a stakeholder analysis. All data fields are listed in Appendix H We use these different sources in order to make the model as complete as possible for all stakeholders. The relevance of each source is discussed separately.

The established data fields from the literature and KYP are brought together to extract one list of data fields important for Nijhuis. The stakeholder analysis is then used as a verification of the selected data. This list is transformed into a data model.

5.4.1 Scientific literature

One of the sources used to establish valuable data field for a data model of a work package is scientific literature. In chapter 3 we reviewed WBS and dug deeper into work packages and CWP's.

5.4.2 Project schedules from KYP

KYP is a planning tool used by Nijhuis. Currently, employees of Nijhuis use this tool to visualize the schedule for both themselves and subcontractors. The tool shows what task has to be done, when it has to be finished and what party is responsible. In addition, it gives the opportunity to attach files like drawings and send messages to stakeholders of the project. This tool is used to subtract data fields from, because it is accepted within the company and therefore widely used. KYP Projects is assessed in Appendix G. The appendix provides screenshots of the tool, along with an explanation of the functionalities of KYP.

5.4.3 Stakeholder analysis

A stakeholder analysis identifies people who are involved in the system. After identification of the stakeholders, they are analysed and relevant data fields are deduced. The stakeholder analysis can be found in Appendix E.

For the creation of a data model for work packages, the stakeholder analysis serves as a verification. The analysis is meant to represent the needs of every stakeholder and can therefore verify whether the necessary data fields are implemented in the model.

5.5 Conceptual data model

Now that we have assessed the sources that are used as input for the data model, it is time to construct the model. The starting level for the data model is the conceptual model. In order to create this model, we first list all data fields that have come forward in the assessment of the sources. This list of data fields can be found in Appendix H. The fields are grouped by the source from which it is extracted.

The second step is to categorize the data fields. We want to use as few categories as possible, while covering all variables and maintaining a logical division of the data fields. The established categories and their allotted data fields can be found in Appendix I. For the conceptual model only the names of the categories necessary.

A conceptual model only consists of entities and relationships. Thus, the names of the categories from the list of data fields serve as the titles of the entities. After creating the entities, the relationships are added. Figure 18 shows the conceptual data model. Our data model represents the data structure of a CWP. Therefore, Task is the main entity in the model. Relationships that are established in the conceptual data model all originate from this entity.

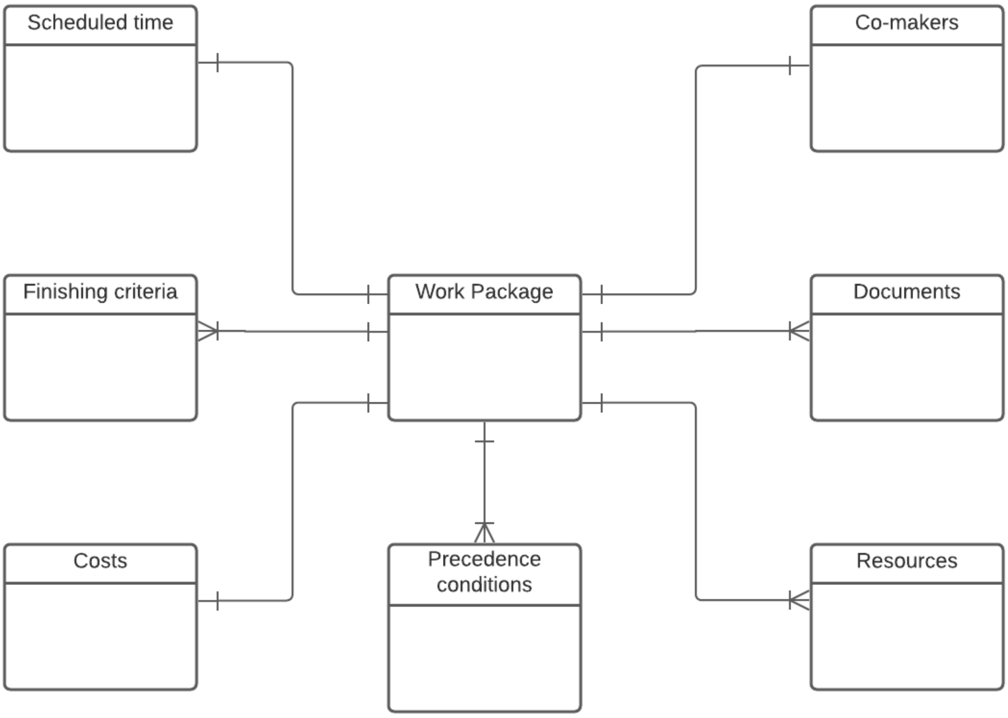


Figure 18: Conceptual data model

The conceptual data model in Figure 18 is explicitly a model for a constrained work package, because the model contains the entity "Precedence conditions". Without this entity, the model displays all data fields necessary to record a normal work package. This work package could even be scheduled and scheduling information would be stored in the "Scheduled time" entity. However, without information on precedence conditions, it would be impossible to know what work package has to be executed first or what work packages are constrained by the execution of others.

5.6 Logical data model

With the conceptual data model as a starting point, we need to add the data fields mentioned in Appendix I to create our logical data model, presented in Figure 19. This model is more or less equal to the final data model that we will establish. All data fields from Appendix I are used to establish the logical data model. Overlapping data fields from the different sources are merged to avoid ambiguity.

The "Work package" entity is surrounded by other entities that are derived from data fields, called attributes, that together represent the CWP. The "Work package" entity contains attributes that are closest related to carrying out a work package. The surrounding entities dive deeper into these attributes that are represented in the main entity. In other words, attributes in the "Work package" entity are often the main subjects of the surrounding entities that contain more detailed attributes regarding that subject.

The "Precedence conditions" entity serves as a checklist for scheduling. As mentioned, without this entity, the data model is merely a representation of a work package without constraints. The checks proposed in the literature by Choo et al. 1998, enable software to validate the correctness of a generated schedule. In Figure 19 the "Precedence conditions" entity is abbreviated, but the attributes entail the questions presented in Appendix A.

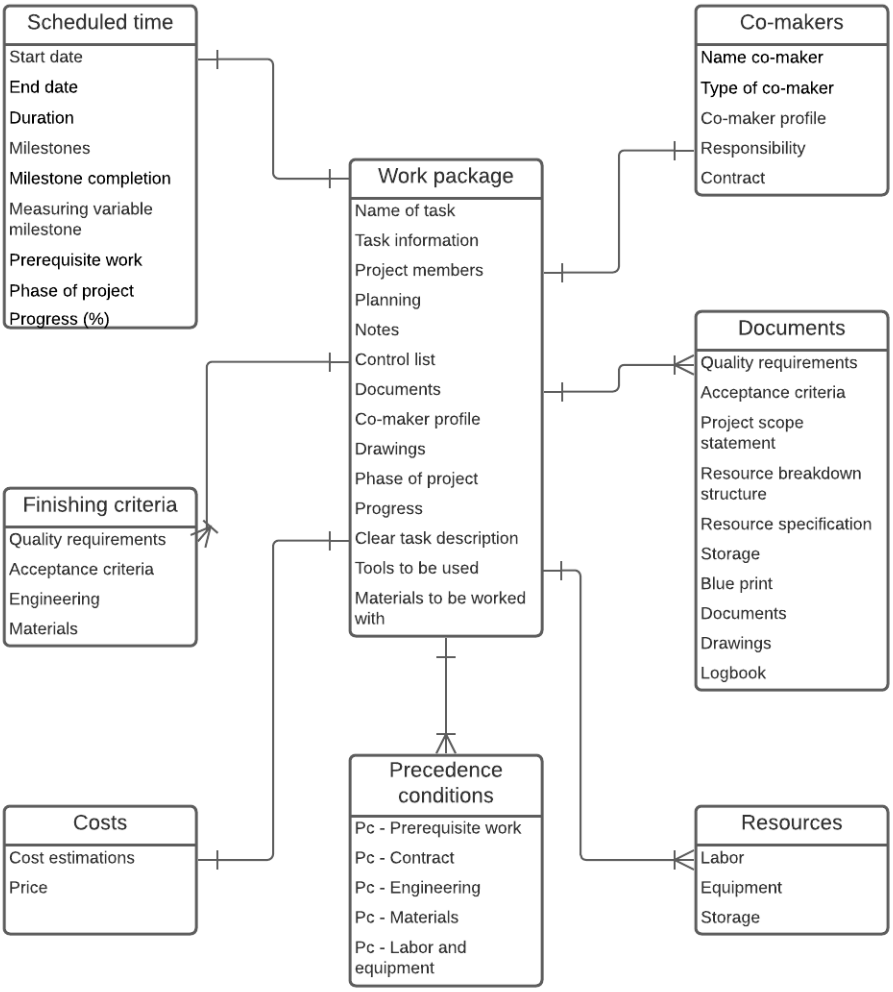


Figure 19: Logical data model

5.7 Physical data model

As a last step, we create our final data model for a CWP, the physical data model, presented in Figure 20. Names of the data fields have been changed to database compatible ones and data types have been added between brackets. Overall, databases do not support the usage of spaces between words, therefore it is customary to use underscores instead of spaces. This prevents a system from causing errors while handling data. Most of the changes in the model speak for itself, because of similarities with the logical data model. However, there are two cases that deserve further explanation.

"Name of task" from the logical data model, is not changed to "Name_of_task" in the physical model, but to "Work_Package_ID" instead. In the field of data the usage of ID's is essential. When data is stored, computer systems could use the data to calculate outcomes for instance. In our case, a system would use data to generate a schedule. In section 4 we established that the Trento process could be seen as a network of interdependent work packages. When a system wants to compile these packages and form a project schedule, the ability to distinguish packages is key. An ID is usually a code name and consists of both letters and numbers. Code names can be built up by an abbreviation of the name of the task in combination with the name of the project and a date. For a computer system every work package should have its own unique code, also known as a primary key. When information on a specific work package is requested, there is no doubt whether it is the right package, because there is only one package linked to that code that the system knows. Think of a work package that has to be carried out more than once for one Trento house. If a project consists of multiple houses and the company is carrying out multiple projects simultaneously, a computer system that records work packages would break without using primary keys. Therefore, the primary key "Work_Package_ID" appears in every entity. Information on documents, quality requirements or deadlines, can now be easily requested to a system using the code name of the work package.

The second point of attention are duplicate data fields. Particularly in the "Documents" we see several data fields that also appear in other entities. However, even though the data fields are identical, the data type is different. This is the case for the attribute "quality requirements" for instance. The reason behind this, is that a work package should be readily comprehensible as stated in section 5.2. Therefore, a distinction has been made between a checklist containing all quality requirements with data type boolean and a document with a string data type, which represents documents containing elaborated explanations regarding these quality requirements.

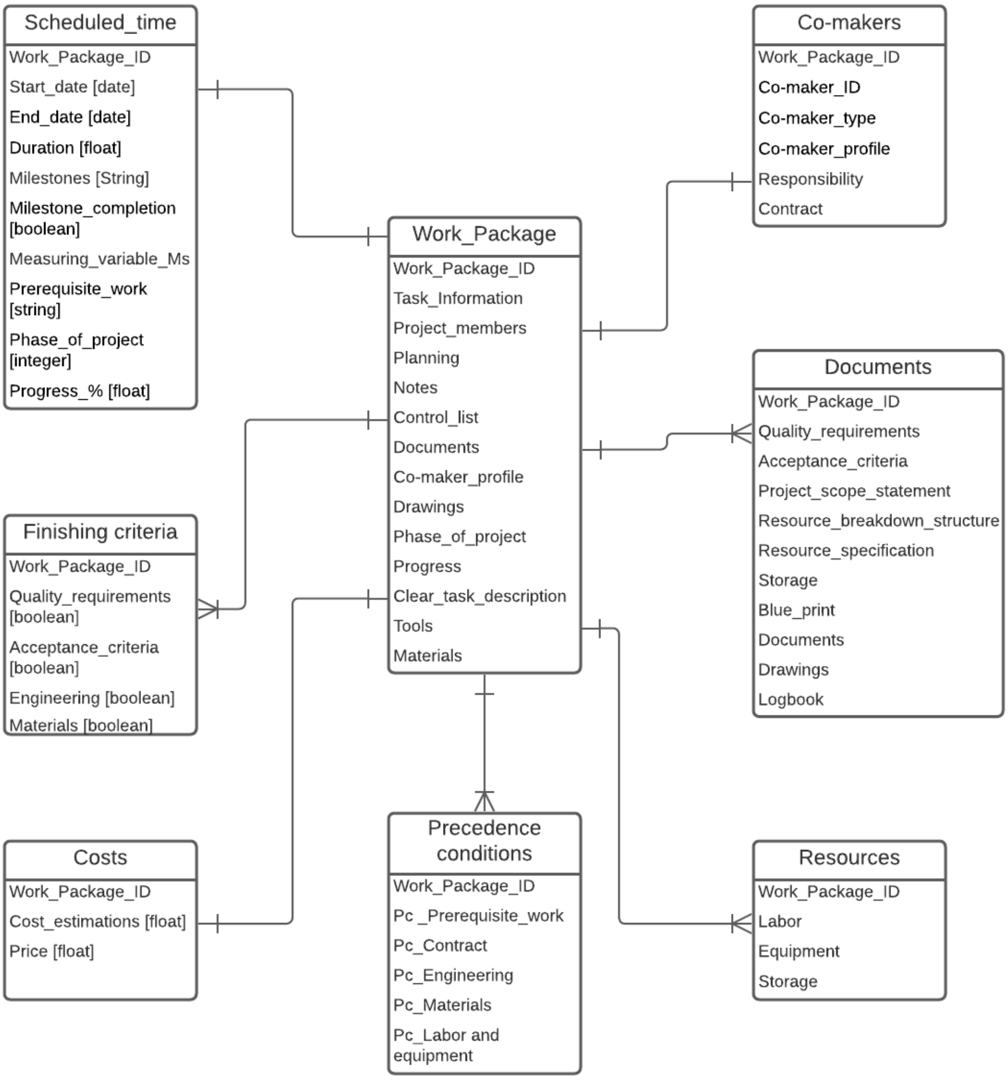


Figure 20: Physical data model

5.8 Evaluation of the data model

In 5.2 we have established three requirements that should be met by the model. First, the data model should be usable for every work package. The created data model manages to cover all fields deduced from the stakeholder analysis (Appendix E). A work package constructed according to the presented data model has the ability to carry information for any stakeholder. Therefore, it seems to usable for every work package existing in the Trento process. In addition, the final result of the data model has a structure with the "Work_package" entity at the centre. Extra entities can be easily linked using this central entity. If the current physical data model misses data fields that would benefit stakeholders, these data fields can be added to the structure.

Second, the data model needs to make sure that it makes work packages workable for every stakeholder. A work package is considered workable, if the data fields deduced from the stakeholder analysis are covered. The stakeholders now have access to their essential data fields. Another component of the workability of a work package is the size. However, the sizing of work package is not in the scope of our research. Hence, covering the deduced data fields from the stakeholder analysis is sufficient to assure the workability of a work package.

Third, the data model needs to make sure that work packages are readily comprehensible and should only contain the essential information. Using different views in the structure of the data model, the available information of the work package is more explicit. The "Work_package" entity contains all general information on a particular task. If one wants to have information regarding the scheduling of the work package, the "Scheduled time" view contains more detailed data. In addition, the data model is kept simple by using a document section. This library contains more in depth information on subjects like quality requirements, while the short versions of these documents are presented elsewhere in the model.

5.9 Conclusion

The WBS method enhances project monitoring, because work packages can be tracked individually. To be able to implement a work package into a system that monitors them, it is important to establish a data model that covers all essential data fields that should be contained by a work package to improve project control. We have covered the essential data fields for a work package by merging them from both the literature and their current planning system, KYP. The literature and a stakeholder analysis validate the correctness of the data fields gathered.

Adding a "Precedence conditions" entity to the data model, equips the work package with information used for scheduling purposes. Precedence conditions of different subjects serve as a checklist to validate whether a work package can be released for execution.

In cooperation with the company we established three acceptation criteria for the data model, that is created in three steps. After evaluating the model according to these three criteria in combination with the stakeholder analysis, we conclude that the data model meets the criteria. The structure is usable for every work package, makes work packages workable for every stakeholder and is readily comprehensible.

6 Conclusion and discussion

In this chapter we answer our research questions established in 2. Answers to the sub-questions will together form the answer to the main research question of this thesis. In addition, we discuss the conclusions, limitations and possible future work.

6.1 Conclusions

The challenge that Nijhuis Bouw is currently facing is that they want to get more grip on project schedule development and project control. In 1.2.2 we have pointed out that an unsuitable method for project planning and control is their underlying core problem. Solving this problem, will put them a step closer towards their goal.

The associated main research question has to provide us with insight into what would be a suitable method for planning and control and how this method could be shaped to fit the Trento construction process. Hence the main research question is:

How should a new method for planning and control be shaped to fit the needs of the Trento Construction concept at Nijhuis Bouw?

In order to answer this question, sub-questions are created to structurize the research and build an answer step by step. Each chapter in this report is devoted to a sub-question. The sub-questions will be answered in section 6.1.1.

6.1.1 Sub-questions

A literature study on existing methods and theories for the development of a method for planning and control has been conducted in 3. Two methods have come forward in this study; beginning-to-end and top-down. The latter, also known as the WBS method is selected of the most suitable for Nijhuis. It provides a solid basis for project planning and supports the division of responsibility and automatic schedule generation. The methodology is widely used within the construction industry. After a more thorough examination of the method we have established that due to the make-to-order nature and recurring activities in the Trento process, a product-oriented WBS with a deliverable-oriented formulation fits the company best.

After a literature study on process modelling techniques, the BPMN method has been chosen to model the Trento process. A comparative analysis has shown that the theoretical Trento concept is a standardized form of building that has been put into practise. Therefore we could model the reality of the Trento Construction process according to its template. In addition to this process model of the full process, a second process model is created. This in depth version of an interval of the original model proofs the theory on CWP's examined in 3.

A data model in the form of an ERD was created in three steps, to shape the WBS method to the needs of Nijhuis. The model is validated with scientific literature and the scheduling software KYP, that Nijhuis is currently using. After assessment of the model using three requirements that are established in cooperation with the company and the stakeholder analysis of Appendix E, we conclude that the data model fits the needs of Nijhuis Bouw.

6.1.2 Main research question

A new method for planning and control in Trento Construction should be shaped by using a product-oriented WBS with a deliverable-oriented formulation. Work packages from this WBS have to be equipped with precedence conditions in order to upgrade them to constrained work packages, which are suitable for generating schedules automatically. The Trento Construction concept has a make-to-order nature and therefore consists of several recurring processes. In order to generate schedules automatically and enhance the overall project control, constrained work packages have to be implemented in the internal processes of the company. However, this implementation demands for a thorough analysis of the full Trento Construction process to identify the constraints for each work package. A network of CWP's can only be set up when the constraints for every work package have been mapped.

6.2 Limitations

Now we will discuss a few limitations that have to be kept in mind when reading this thesis.

This thesis is written in order to complete the bachelor of Industrial Engineering and Management at the University of Twente. For this bachelor thesis there was limited time available which restricts the level of detail in which this research has been carried out.

The Trento Construction process is both developed and patented by Nijhuis Bouw. The extent to which this construction method is standardized, is uncommon in the literature. This makes it hard to generalize an outcome or to interpret literature from a Trento point of view.

This research is carried out during the COVID-19 pandemic. In several ways, this pandemic restricts the possibilities to collect data or gather information from the company. Even though the consequences of this set back have been partially absorbed by organizing online meetings, not being able to meet people physically leads to inefficiency in the process.

Not all interviews could be recorded due to confidentiality. During these interviews notes had to be taken. This makes it more difficult to provide the most accurate representation of an interviewee's answers in the research.

The thesis written serves as a proof of concept. The company is looking for a method to enhance planning and control for Trento an additionally wants to know how this new method should be shaped. There is no environment available in which findings could be put to the test, for instance in terms of comparing literature to company data. Therefore, the research remains a theoretical perspective on a possible future for Nijhuis.

6.3 Future Work

Lastly we will revisit some parts of the research to point out what could be investigated more detailed and we will discuss interesting topics for further research.

The current research is conducted on the construction of a single house. The theory on constrained work packages can be clearly presented when we focus on one house. If the precedence conditions of all work packages involved are mapped, a computer system is able to construct such a planning. However, when multiple houses are involved, the theory gets more intricate. To improve this thesis it would be interesting to dive deeper into projects involving multiple houses and investigate how a network of constrained work packages behaves in these type of environments.

In the data model there are a few data fields that appear more than once. In particular, the "Document" entity contains attributes like quality requirements or acceptance criteria which also appear elsewhere, because the entity functions as library. Outside the "Document" entity these data fields are meant to be presented in a more compact manner. For a future research it would be useful to investigate to what extend data fields need to be presented in a view, when elaborated information on the data field can be found elsewhere.

In this thesis we established that a network of constrained work packages supports automatic schedule generation. To make this work, constraints for all work packages need to be mapped in order to create a network. Valuable for this mapping would be to investigate the feasibility of identifying the constraints for every work package involved in the Trento Construction process.

A subject that has briefly been mentioned in section 3, but has not been worked out in this thesis is the sizing of a work package. Colenso 2000 states that the desired level of detail is dependent on different factors like risk, complexity and desired level of control. Hughes 1986 states that for every project there is an optimum size for a work package in every project. The sizing of a work package is fundamental in the creation of a WBS, hence it is interesting for Nijhuis to look into this topic.

Another interesting topic for further research is machine learning. After an extensive literature review, Amer, Koh, and Golparvar-Fard 2021 addresses that automatic schedule generation in the traditional construction industry if difficult. The author writes however, that due to the rapid developments on in the field of machine learning this might be a solution for the future. Hence, research in the possibilities for machine learning in automatic schedule generation is a topic for future research.

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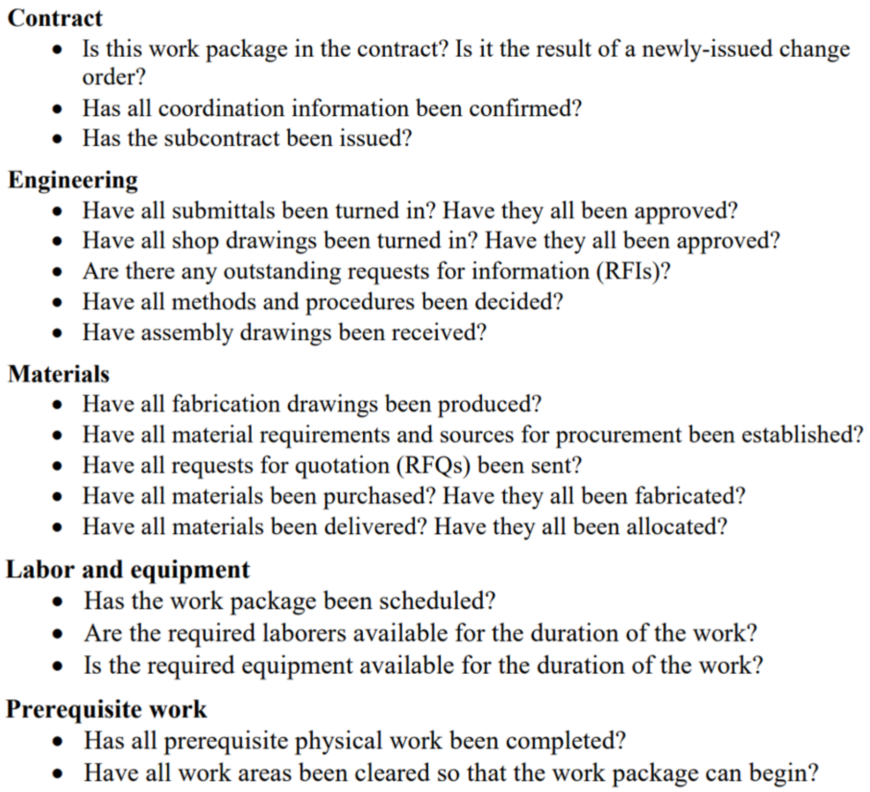
Appendices

Appendix A Work package constraints



Contract

- Is this work package in the contract? Is it the result of a newly-issued change order?
- Has all coordination information been confirmed?
- Has the subcontract been issued?

Engineering

- Have all submittals been turned in? Have they all been approved?
- Have all shop drawings been turned in? Have they all been approved?
- Are there any outstanding requests for information (RFIs)?
- Have all methods and procedures been decided?
- Have assembly drawings been received?

Materials

- Have all fabrication drawings been produced?
- Have all material requirements and sources for procurement been established?
- Have all requests for quotation (RFQs) been sent?
- Have all materials been purchased? Have they all been fabricated?
- Have all materials been delivered? Have they all been allocated?

Labor and equipment

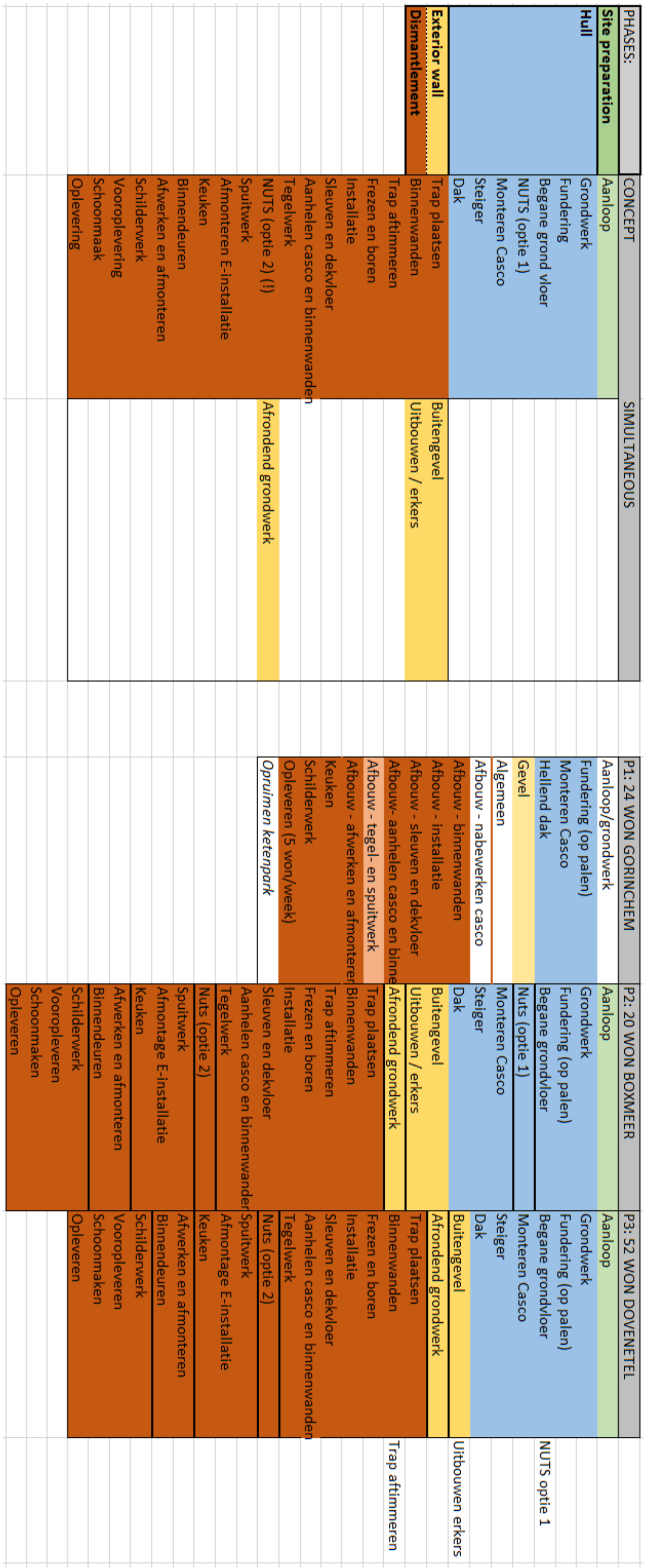
- Has the work package been scheduled?
- Are the required laborers available for the duration of the work?
- Is the required equipment available for the duration of the work?

Prerequisite work

- Has all prerequisite physical work been completed?
- Have all work areas been cleared so that the work package can begin?

Figure 21: Work package constraint topics, from Choo et al. 1998

Appendix B Project Schedule Analysis



PHASES:
Site preparation
Hull
Exterior wall
Dismantlement

CONCEPT
Aanloop
Grondwerk
Fundering
Begane grond vloer
NUTS (optie 1)
Monteren Casco
Steiger
Dak
Trap plaatsen
Binnenwanden
Trap aftimmeren
Frezen en boren
Installatie
Sleuven en dekvloer
Aanhelen casco en binnenwanden
Tegelwerk
NUTS (optie 2) (!)
Spuitwerk
Afmonteren E-installatie
Keuken
Binnendeuren
Afwerken en afmonteren
Schilderwerk
Vooroplevering
Schoonmaak
Oplevering

SIMULTANEOUS
Buitengevel
Uitbouwen / erkers
Afrondend grondwerk

P1: 24 WON GORINCHEM
Aanloop/grondwerk
Fundering (op palen)
Monteren Casco
Hellend dak
Gevel
Algemeen
Afbouw - nabewerken casco
Afbouw - binnenwanden
Afbouw - installatie
Afbouw - sleuven en dekvloer
Afbouw- aanhelen casco en binne
Afbouw - tegel- en spuitwerk
Afbouw - afwerken en afmonteren
Keuken
Schilderwerk
Opleveren (5 won/week)
Opruimen ketenpark

P2: 20 WON BOXMEER
Aanloop
Grondwerk
Fundering (op palen)
Begane grondvloer
Nuts (optie 1)
Monteren Casco
Steiger
Dak
Buitengevel
Uitbouwen / erkers
Afrondend grondwerk
Trap plaatsen
Binnenwanden
Trap aftimmeren
Frezen en boren
Installatie
Sleuven en dekvloer
Aanhelen casco en binnenwanden
Tegelwerk
Nuts (optie 2)
Spuitwerk
Afmontage E-installatie
Keuken
Afwerken en afmonteren
Binnendeuren
Schilderwerk
Vooropleveren
Schoonmaken
Opleveren

P3: 52 WON DOVENETEL
Aanloop
Grondwerk
Fundering (op palen)
Begane grondvloer
Monteren Casco
Steiger
Dak
Buitengevel
Afrondend grondwerk
Trap plaatsen
Binnenwanden
Frezen en boren
Installatie
Sleuven en dekvloer
Aanhelen casco en binnenwanden
Tegelwerk
Nuts (optie 2)
Spuitwerk
Afmontage E-installatie
Keuken
Afwerken en afmonteren
Binnendeuren
Schilderwerk
Vooropleveren
Schoonmaken
Opleveren

NUTS optie 1
Uitbouwen erkers
Trap aftimmeren

Figure 22: Project schedule analysis

Appendix C Trento Concept model

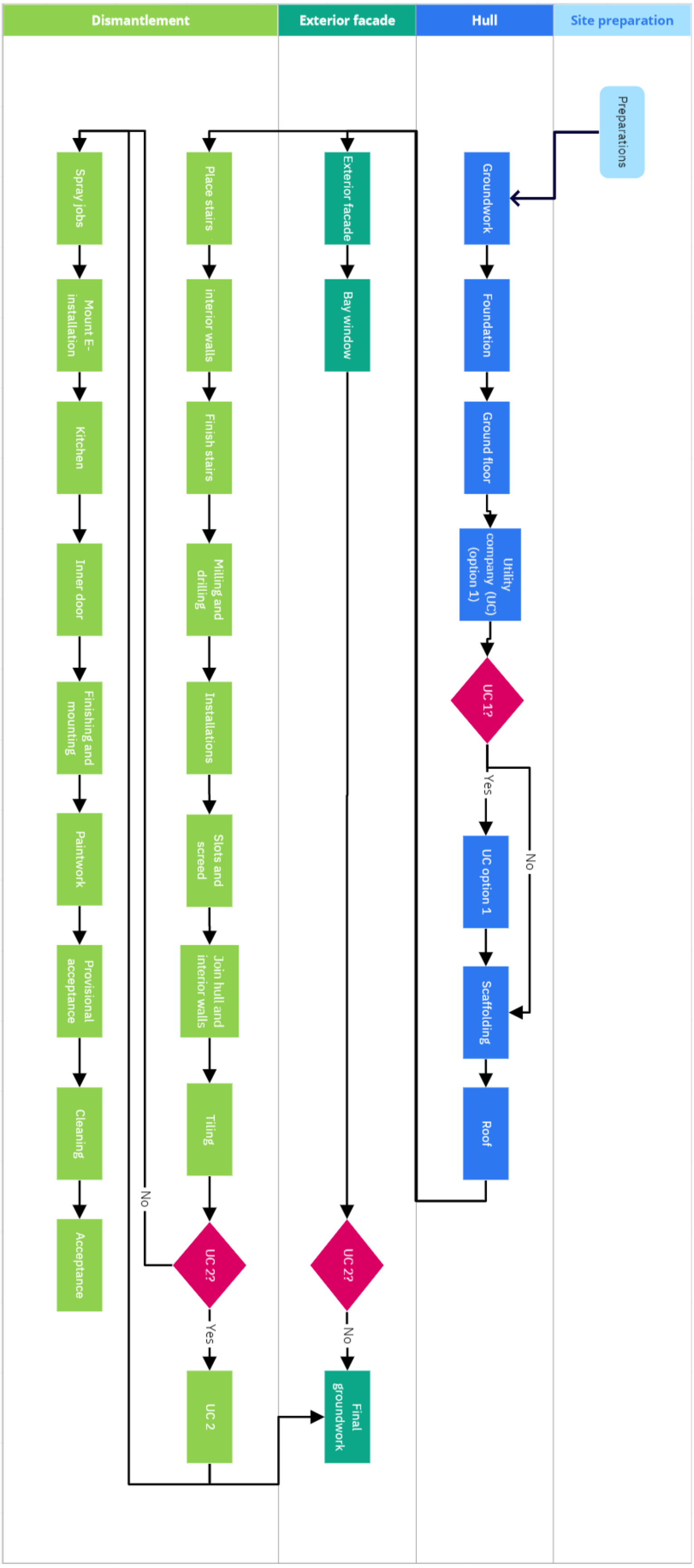


Figure 23: A model of the Trento Concept using the BPMN method

Appendix D Trento BPMN Zoomed In

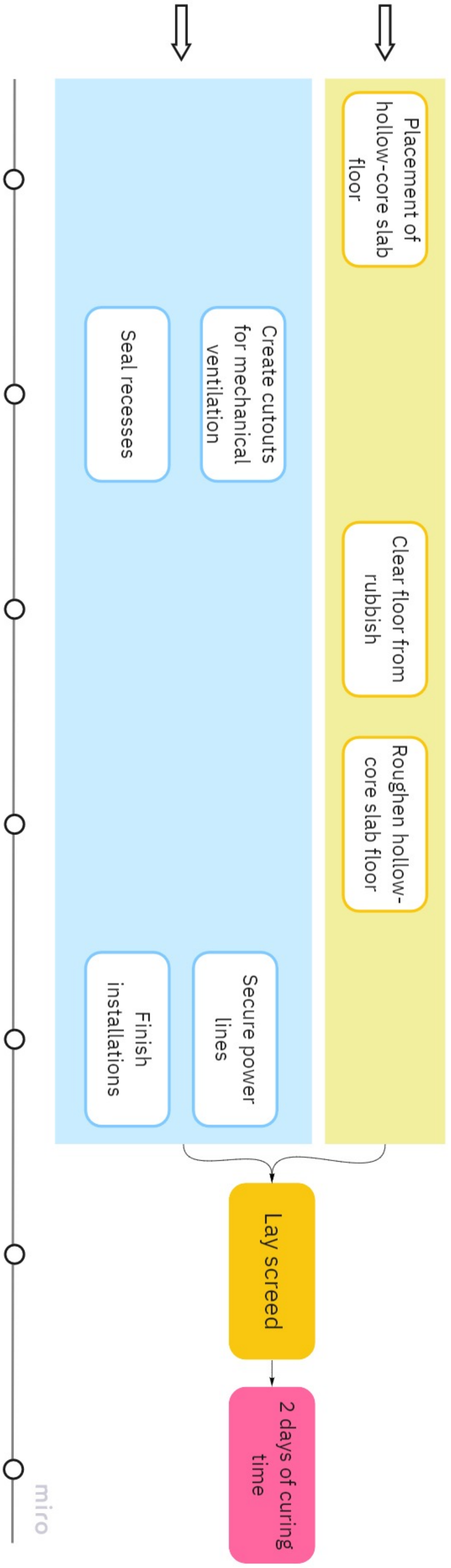


Figure 24: An in depth model of a part of the Trento Concept using the BPMN method

Appendix E Stakeholder Analysis

In order to find data streams that should be recorded for the data model in section 5.4, we perform a stakeholder analysis. This analysis shows the people involved in the system and helps identify their interests. It is important that every user of the system gets the information they need. Hence, we analyse these different users and their need of specific data.

Stakeholders involved in a construction project are shown in figure 25. For every stakeholder, their role in a construction project and involvement in the system is explained.

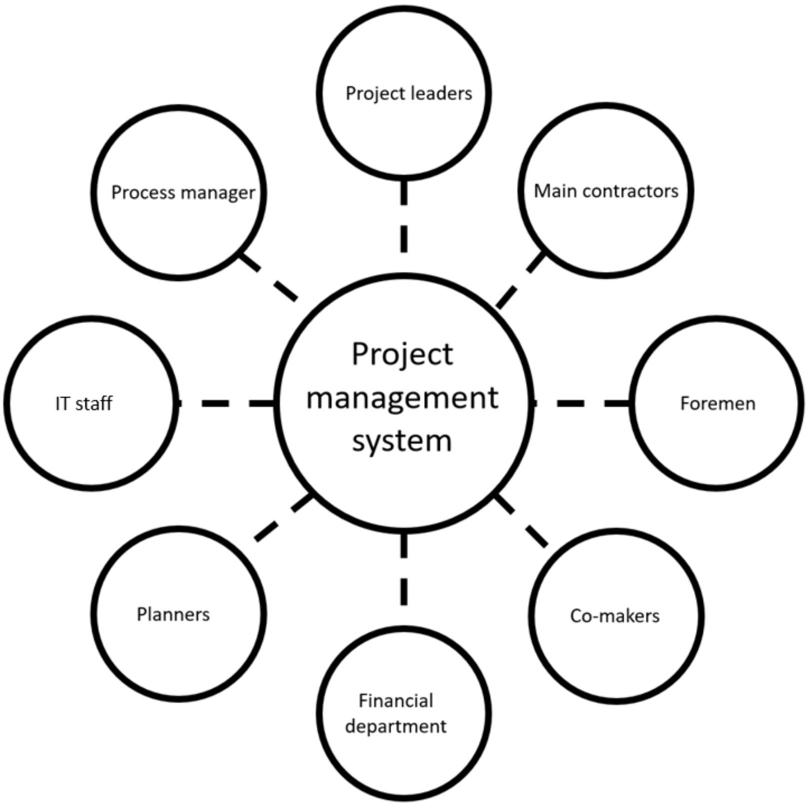


Figure 25: Stakeholder diagram

Appendix E.1 Project leaders

Project leaders are responsible for a project on a strategical level. They maintain the relationship with co-makers and inform them on time. Prior to the start of a project, project leaders work out the financial allocation of the project. In addition, they determine the budget available for resources or make decisions about resource specifications and storage.

A project leader is not involved with problems that could be solved within a week, occurring on the construction site. However, if there is problem that is bigger than operations at the construction site, the project leader will try to solve it. An example is a supplier that systematically fails to deliver in time.

A project leader demands for information on the status of the project. Important for this role is to know whether milestones are reached in time. For this purpose, a display of the percentage of completed work packages per phase is useful.

Appendix E.2 Main contractors

Main contractors manage a project on a tactical level. They are on site most of the week and are the leader there. Main contractors direct the co-makers, pay close attention to the progress of the project in relation to the schedule and keep track of the project budget. They are also responsible for the quality. Therefore, they regularly need to walk around the construction site to do inspections and talk to the foremen about their progress.

When problems occur at the construction site, main contractors will try to solve those. If the problem is bigger than just the construction site and occurs systematically, the main contractor can reach out to the project leader.

To be able to instruct co-makers at the construction site, a main contractor needs blueprints and a clear description of the task. This came forward in a structured interview with a main contractor of Nijhuis. The questions of this interview are in Appendix F. On a construction site, different parties operate simultaneously but depend on each other. Clear descriptions are then crucial for the progress of the work.

Appendix E.3 Foremen

A foreman is the leader of a specific group of the construction workers. Foremen carry responsibilities on an operational level. Usually, the main contractor assigns tasks to the foremen. Foremen then carry out the tasks together with other construction workers and communicate the progress with the main contractor.

When a problem occurs at the construction site, a foreman communicates the problem with the main contractor who tries to solve it or informs the project leader.

A foreman does not need to have the complete picture, but needs to know exactly what actions are involved in the task and sub-tasks he is responsible for. Therefore, next to blue prints and a clear description of the task and its sub-tasks, a foreman needs practical information. This involves information about: the tools to be used, the materials to be used and a deadline.

Appendix E.4 Co-makers

Co-makers are subcontractors with a business relation to Nijhuis Bouw. Nijhuis aims to maintain a good relationship with these companies to be able to cooperate as smoothly as possible with them. This has a positive influence on the execution of a project.

Co-makers are the executive force. They follow the instructions from the main contractor, given to them via the foreman. Co-makers will have minimum access to the system. They need to have clear instructions, blueprints and quality requirements of the task at hand. A final check and status update of the task is done by the main contractor.

Appendix E.5 Financial department

The financial departement of Nijhuis keeps track of the company's financial capital. Every running project has a project number. The financial department monitors what costs are being booked on these projects. In addition to making sure that projects stay within the limits of the budget, the financial department also ensures that co-makers or other cooperative parties receive their money.

What this means for the system is that the financial department needs link costs to certain items. As an example, lets say a main contractor hires an extra construction trailer. The main contractor makes the order, but the financial department needs to transfer the money to the owner of the trailer. Therefore, employees of the financial department benefit from product IDs. An overview of the company's most ordered products linked to an ID enhances the communication between departments. Next to a product ID, the financial department also needs to know the amount of money and the details of the person or company they need to transfer the money to.

Appendix E.6 Planners

Before a project starts, a planner will create a schedule in cooperation with the main contractor responsible. A main contractor has more construction knowledge whereas a planner has more knowledge on co-makers and their lead times. A planner constantly evaluates the feasibility of the schedule and tries to minimize the risk of delay.

To carry out this job, a planner needs a clear overview of the schedule. Information on tasks, deadlines and milestones is necessary to see what is left to be executed and when this has to be carried out. In addition, a planner needs to know what party is responsible for which work package, together with their contact details. A nice to have would be a completion percentage of the project and insight in the amount of days the project team departs from the schedule.

Appendix E.7 IT staff

The function of IT is in twofold. They facilitate the hardware and they make sure that the software that supports processes is suitable and up-to-date, maintaining or enhancing the overall performance of the company. This second responsibility explains their involvement with a new system.

The IT department is responsible for the foundation of the system. Their interest is to implement an application that fits the needs of end-users. Without a smooth fit, the adoption of a new application is more likely to give resistance.

In terms of data streams, there is no specific data that should be recorded for the IT department. Thong 1999 establishes the "complexity of an information system" and the "information intensity" as two influencing factors for the adoption of a new information system. Therefore, the focus of the IT department is on the look and feel of the system.

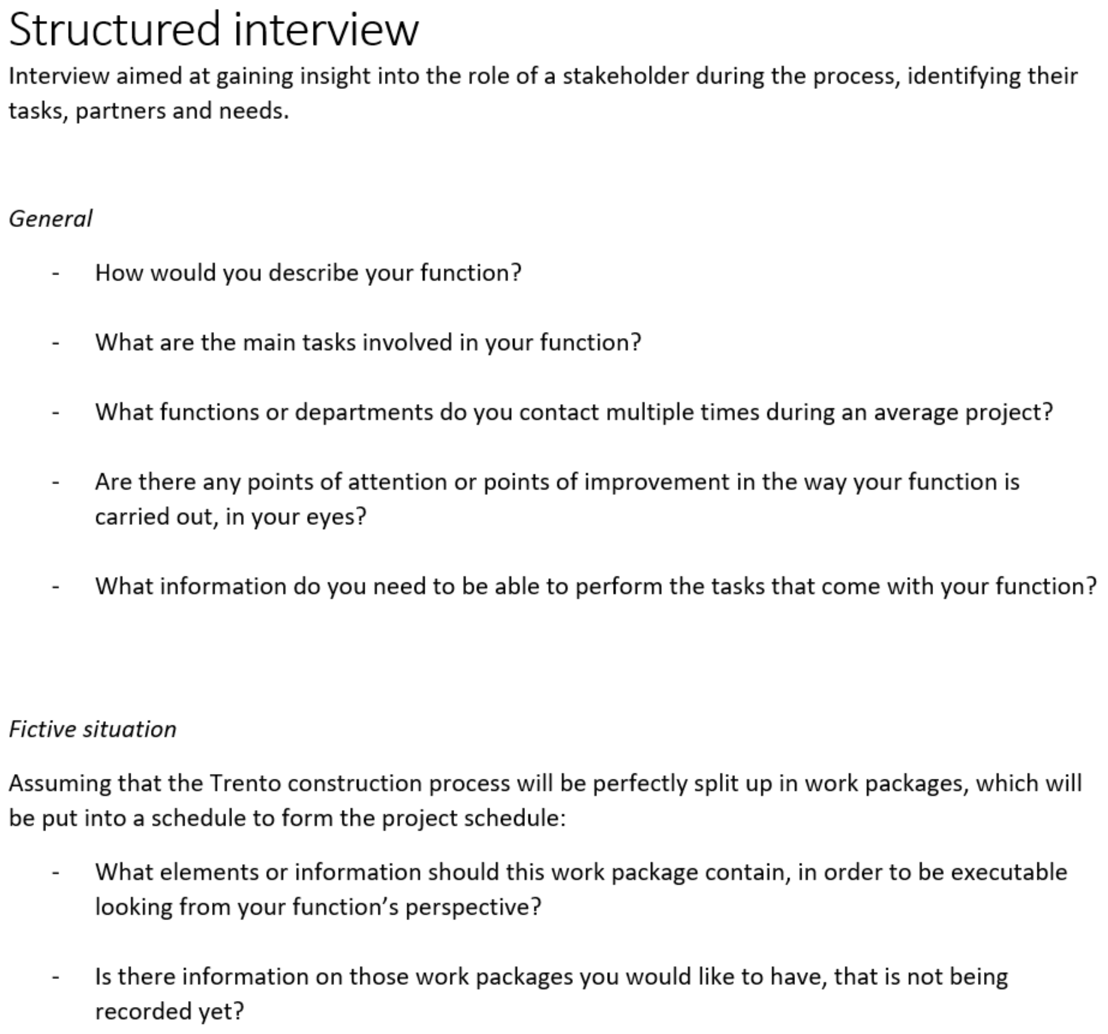
Appendix E.8 Process manager

Process managers look at the process from a distant perspective. They look at how the work is currently completed and try to maintain a critical look towards the process in order to drive innovation. In addition, they assess the companies future, for instance in terms of relationships with housing corporations.

A process manager will look at the implementation from a practical point of view. They verify whether the system is being used as intended and by what stakeholders. If there is the opportunity to alter the system in a way that benefits stakeholders in their usage a process manager will try to propel this change.

In terms of data fields, the responsibility of a process manager does not rely on specific ones. The process manager assesses the system and will share points of improvement along the implementation process.

Appendix F Stakeholder interview



Structured interview

Interview aimed at gaining insight into the role of a stakeholder during the process, identifying their tasks, partners and needs.

General

- How would you describe your function?
- What are the main tasks involved in your function?
- What functions or departments do you contact multiple times during an average project?
- Are there any points of attention or points of improvement in the way your function is carried out, in your eyes?
- What information do you need to be able to perform the tasks that come with your function?

Fictive situation

Assuming that the Trento construction process will be perfectly split up in work packages, which will be put into a schedule to form the project schedule:

- What elements or information should this work package contain, in order to be executable looking from your function's perspective?
- Is there information on those work packages you would like to have, that is not being recorded yet?

Figure 26: Structure of the interview used to interview stakeholders

Appendix G KYP analysis

Appendix G.1 Introduction

The function of this appendix is to show what KYP looks like and what input fields it covers. It contains several screenshot along with explanations of the planning tool. Some of the input fields in screenshots are partially left out. This is done due to privacy reasons.

KYP stands for Keep Your Promise. It is a software tool developed to make the construction industry more efficient. KYP tries to realize this by providing one schedule for all stakeholders of a project and keeping the tool simple. The platform contains a project schedule that can be accessed by all stakeholders. KYP is about visualizing the project schedule and the tasks and responsibilities that come with a specific project. These tasks are addressed to parties that are involved. This way everyone involved knows what is being expected of them. In addition, KYP offers possibilities to connect with each other through their platform. According to KYP Project, the benefits of their platform give users more grip on their planning and enhance the efficiency in construction projects.

Appendix G.2 KYP walk through

When the program opens, the project that the user wants to see can be selected. After selecting a project the User Interface (UI) shown in figure 27 appears:

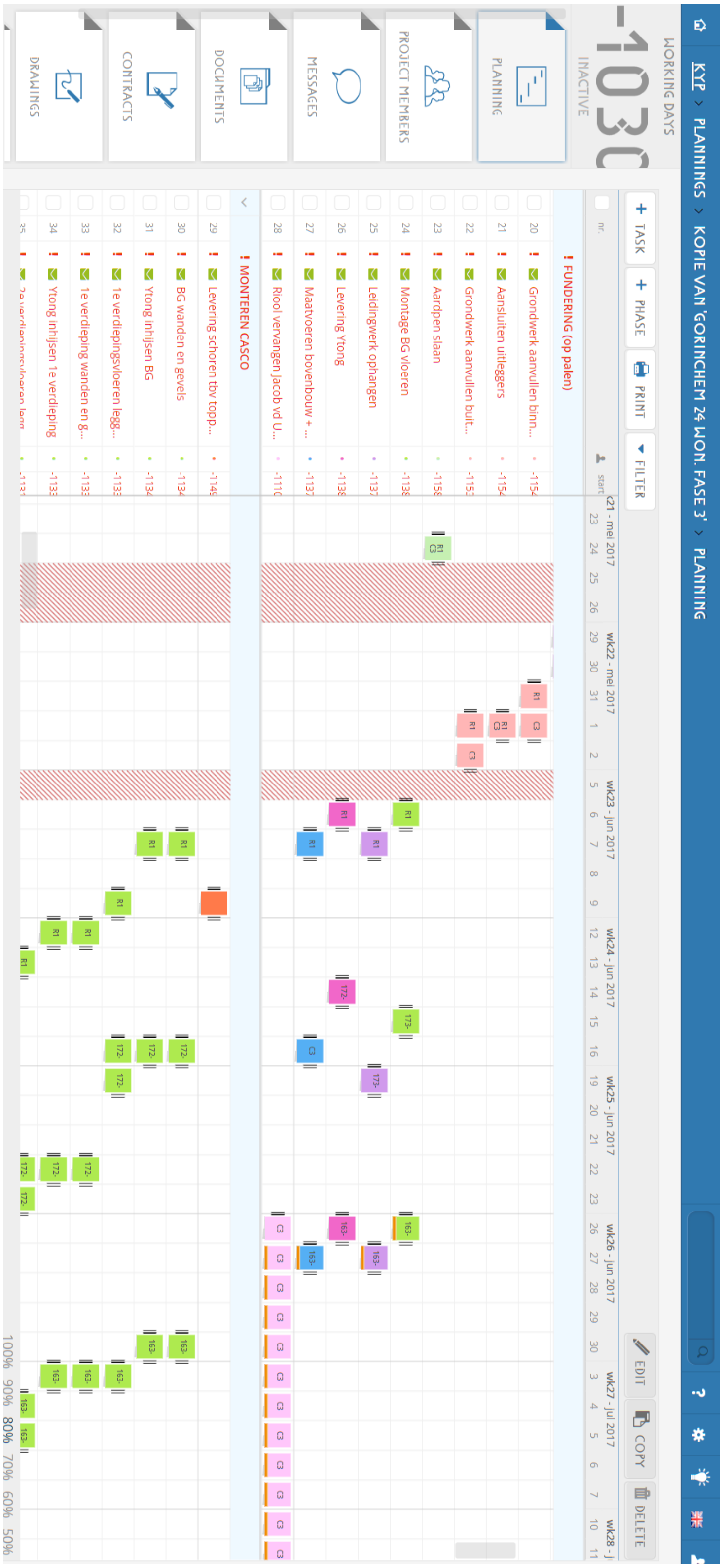
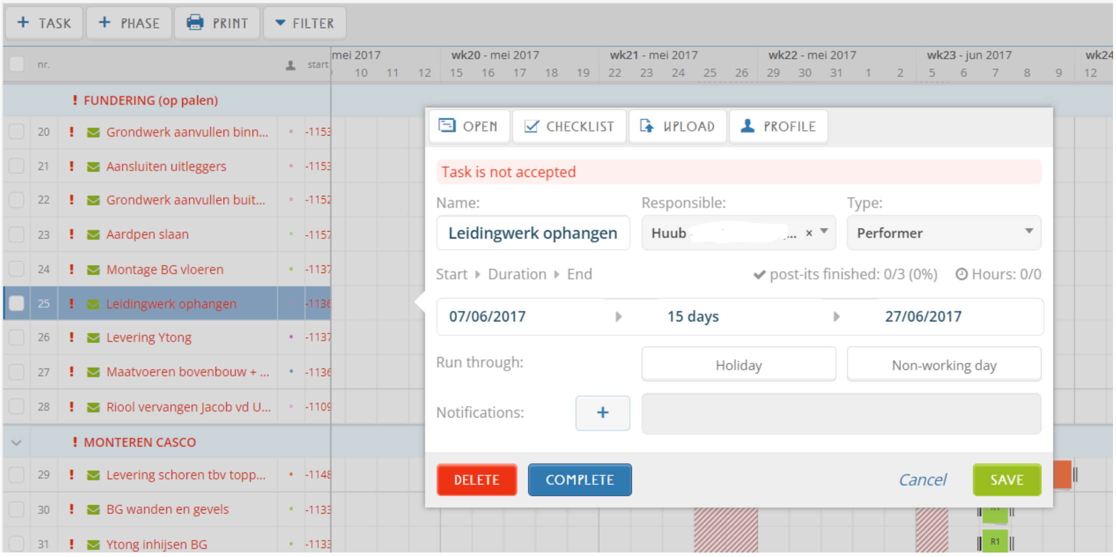


Figure 27: Project homepage in KYP

In the top left corner there is a large number representing the amount of working days there is left to complete the deadline. The screenshot in figure 27 is from an old project. Therefore, the number is a negative amount of working days left. The size of the number indicates the importance of time in the construction industry. Thus, the factor time also plays an important role in the data model.

Figure 27 also shows a part of the project schedule. On the left side the different tasks are mentioned. Each tasks is given its own duration by placing post-its in the schedule. What stands out is that the minimum duration of a task is one day. If a task takes more than a day, the task is scheduled multiple days in a row or is even spread over a variation of days. When the user clicks on one of the tasks to get more information, the pop-up shown in 28 appears.



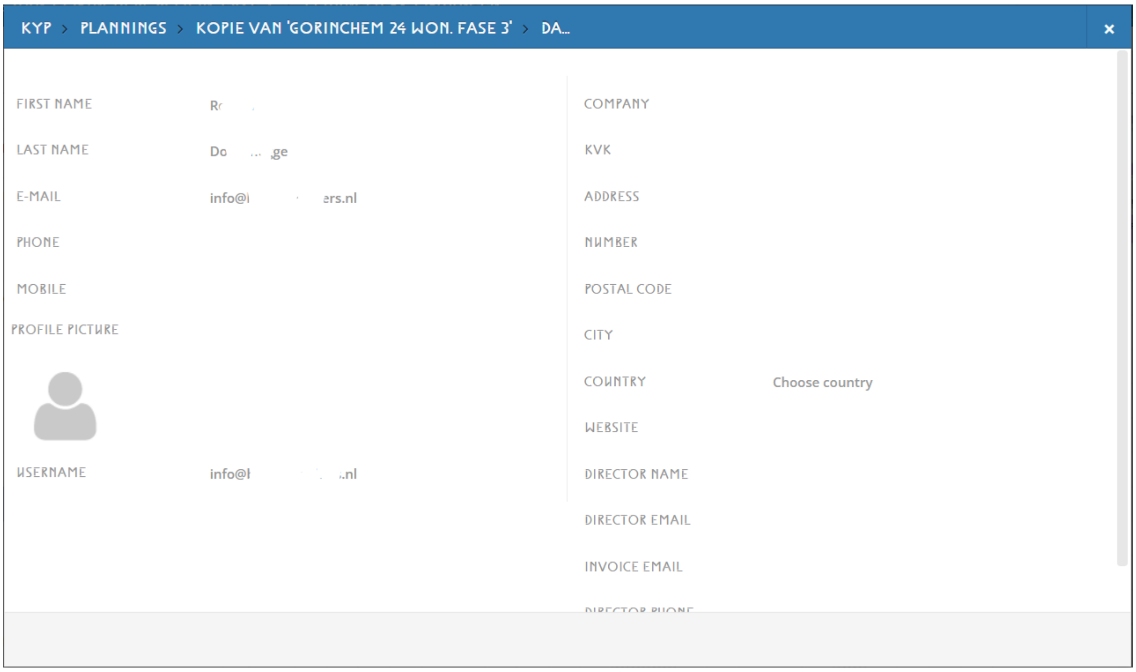
! FUNDERING (op palen)
20 ! Grondwerk aanvullen binn... -1153
21 ! Aansluiten uitleggers -1153
22 ! Grondwerk aanvullen buit... -1152
23 ! Aardpen slaan -1157
24 ! Montage BG vloeren -1137
25 ! Leidingwerk ophangen -1136
26 ! Levering Ytong -1137
27 ! Maatvoeren bovenbouw + ... -1136
28 ! Riool vervangen Jacob vd U... -1109
! MONTEREN CASCO
29 ! Levering schoren tbv topp... -1148
30 ! BG wanden en gevels -1133
31 ! Ytong inhijsen BG -1133

Task is not accepted

Name: Leidingwerk ophangen
Responsible: Huub [redacted] ...
Type: Performer
Start ▸ Duration ▸ End
✓ post-its finished: 0/3 (0%)
Hours: 0/0
07/06/2017 ▸ 15 days ▸ 27/06/2017
Run through: Holiday | Non-working day
Notifications: +

Figure 28: Task pop-up

This task is called "Leidingwerk ophangen" which means "hang pipe system". The pop-up shows the name of the task, person responsible and type of stakeholder. The two types possible are "Performer" and "Supplier". In addition, time constraints can be added. In the header of the pop-up window, there are four buttons. Each button opens its own new window, providing information or fields to post information regarding the particular subject. "Open" provides a navigation menu similar to the menu on the left of the homepage. "Checklist" gives the opportunity to implement a checklist for a single task, such as hanging the pipe system. "Upload" provides a field where documents such as blue prints could be uploaded. "Profile" contains information about the person responsible, such as: full name, e-mail, phone, company address and director e-mail. Even though KYP provides all these fields, not all of them are being used by Nijhuis. Regarding these 4 buttons, of which 3 give the opportunity to store extra information, only one is being partially used. "Checklist" and "Upload" are empty, whereas "Profile" is filled for 6 out of 18 fields as can be seen in figure 29.



FIRST NAME R[redacted]
LAST NAME Do[redacted]ge
E-MAIL info@[redacted]ers.nl
PHONE
MOBILE
PROFILE PICTURE
USERNAME info@[redacted].nl

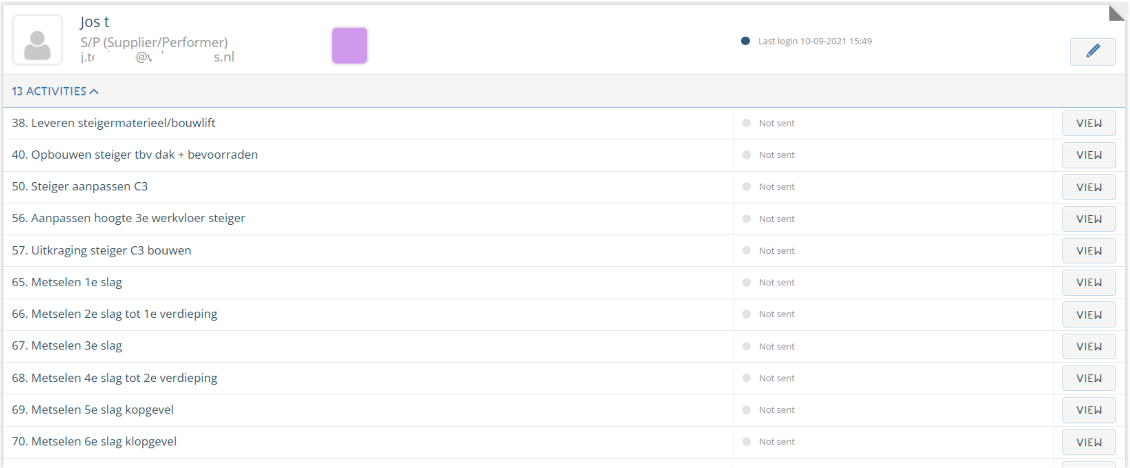
COMPANY
KVK
ADDRESS
NUMBER
POSTAL CODE
CITY
COUNTRY Choose country
WEBSITE
DIRECTOR NAME
DIRECTOR EMAIL
INVOICE EMAIL
DIRECTOR PHONE

Figure 29: Contact pop-up window

The left side of figure 27, contains different buttons for categories that can be selected:

- Planning
- Project Members
- Messages
- Documents
- Contracts
- Drawings
- Logbook

Most of them speak for itself, but we discuss them regardless. The "Planning" menu brings you back to the homepage interface containing the total project planning. The button "Project Members" shows all the stakeholders involved in the project. As mentioned before, there are two types of stakeholders involved in a project that are registered in KYP: performer and supplier. Other stakeholders are excluded from this platform. In this list of stakeholders, each stakeholder is also linked to all the tasks they are responsible for. Figure 30 displays what this looks like on the platform.



Jos t
S/P (Supplier/Performer)
j.t[redacted]@v[redacted]s.nl

● Last login 10-09-2021 15:49

13 ACTIVITIES ^

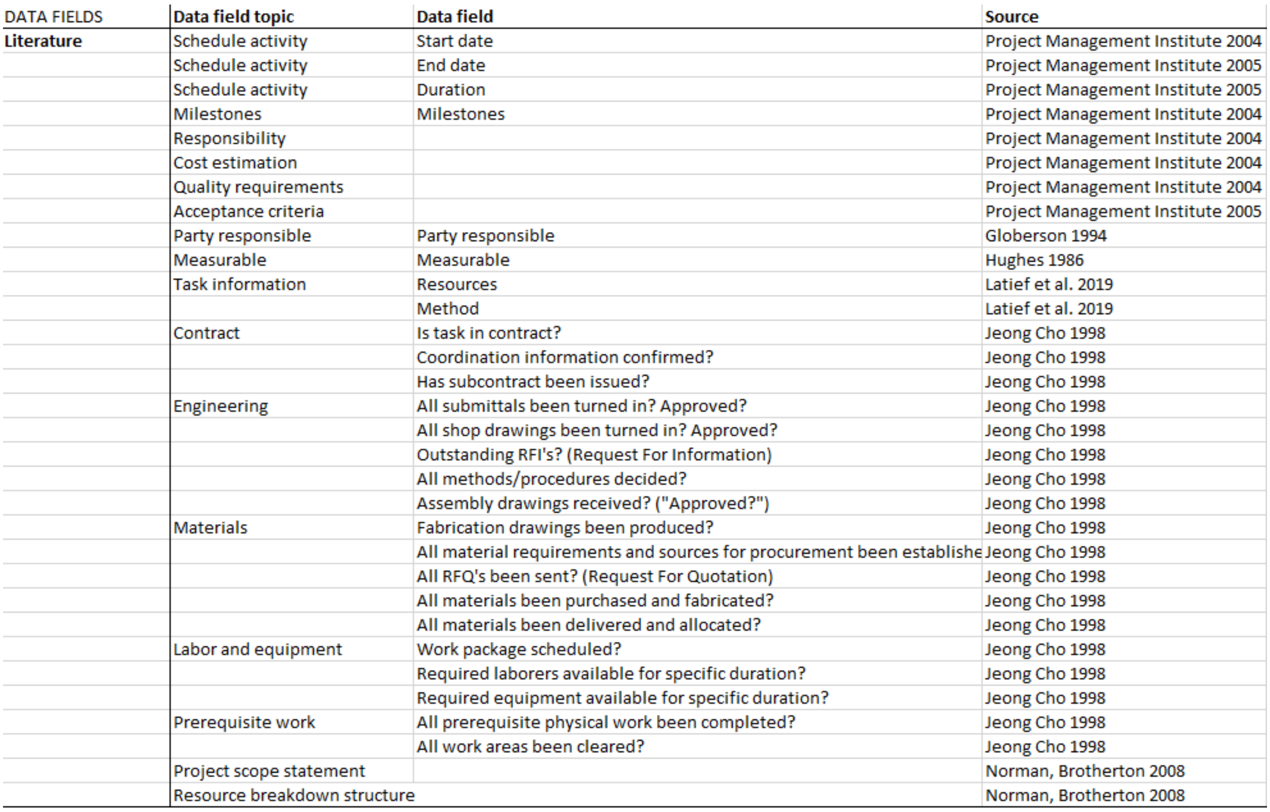
38. Leveren steigermaterieel/bouwlift	● Not sent	VIEW
40. Opbouwen steiger tbv dak + bevoorraden	● Not sent	VIEW
50. Steiger aanpassen C3	● Not sent	VIEW
56. Aanpassen hoogte 3e werkvloer steiger	● Not sent	VIEW
57. Uitkraging steiger C3 bouwen	● Not sent	VIEW
65. Metselen 1e slag	● Not sent	VIEW
66. Metselen 2e slag tot 1e verdieping	● Not sent	VIEW
67. Metselen 3e slag	● Not sent	VIEW
68. Metselen 4e slag tot 2e verdieping	● Not sent	VIEW
69. Metselen 5e slag kopgevel	● Not sent	VIEW
70. Metselen 6e slag klopgevel	● Not sent	VIEW

Figure 30: Responsibilities per stakeholder

"Messages" is an environment to contact stakeholders. In most cases this section was empty. At Nijhuis most questions or handled by phone, so there would be little use for the messages section. However, rarely a message was sent via KYP. For instance about what project number certain materials needed to be booked on. "Documents" is a section that provides a space to upload files, like a bill of materials. "Contracts" and "Drawings" are similar to the "Documents" section. Finally we have the "Logbook" section. Here users can stress events like the start date of the project.

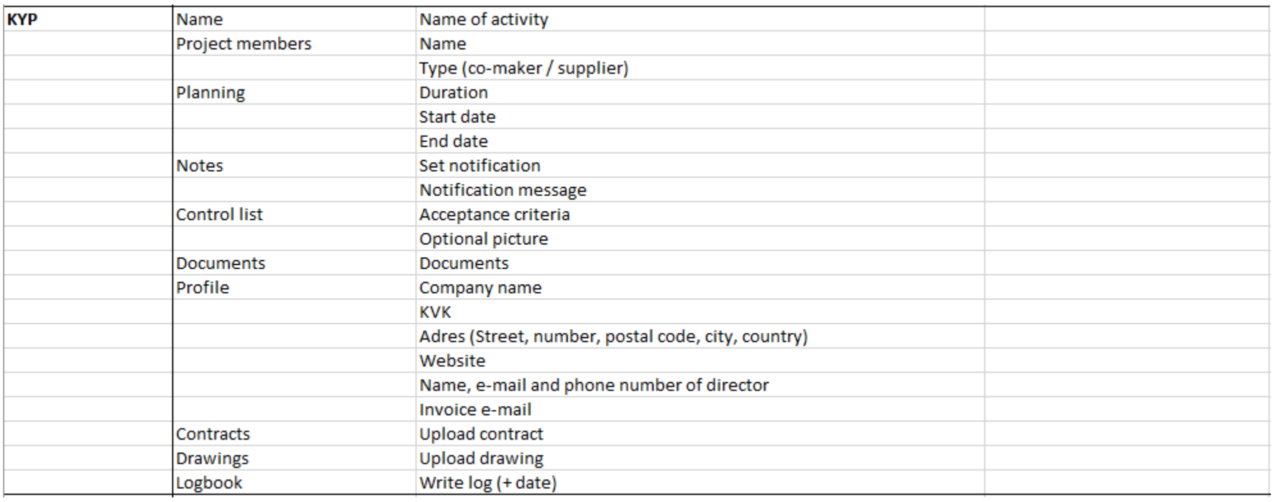
Appendix H Data fields unstructured

This appendix contains a list of data fields that have been collected. Data fields are collected from the literature, KYP and a stakeholder analysis (Appendix E). The data fields presented here are unstructured.



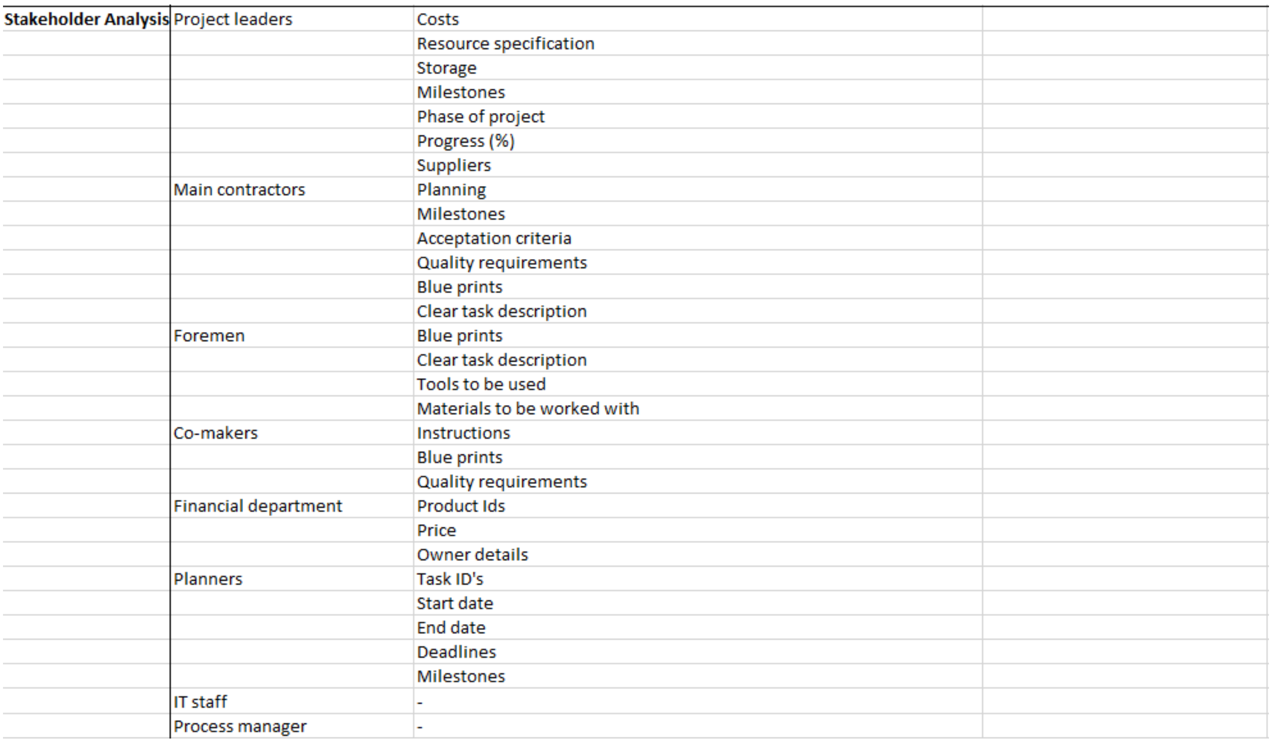
DATA FIELDS	Data field topic	Data field	Source
Literature	Schedule activity	Start date	Project Management Institute 2004
	Schedule activity	End date	Project Management Institute 2005
	Schedule activity	Duration	Project Management Institute 2005
	Milestones	Milestones	Project Management Institute 2004
	Responsibility		Project Management Institute 2004
	Cost estimation		Project Management Institute 2004
	Quality requirements		Project Management Institute 2004
	Acceptance criteria		Project Management Institute 2005
	Party responsible	Party responsible	Globerson 1994
	Measurable	Measurable	Hughes 1986
	Task information	Resources	Latief et al. 2019
		Method	Latief et al. 2019
	Contract	Is task in contract?	Jeong Cho 1998
		Coordination information confirmed?	Jeong Cho 1998
		Has subcontract been issued?	Jeong Cho 1998
	Engineering	All submittals been turned in? Approved?	Jeong Cho 1998
		All shop drawings been turned in? Approved?	Jeong Cho 1998
		Outstanding RFI's? (Request For Information)	Jeong Cho 1998
		All methods/procedures decided?	Jeong Cho 1998
		Assembly drawings received? ("Approved?")	Jeong Cho 1998
	Materials	Fabrication drawings been produced?	Jeong Cho 1998
		All material requirements and sources for procurement been establishe	Jeong Cho 1998
		All RFQ's been sent? (Request For Quotation)	Jeong Cho 1998
		All materials been purchased and fabricated?	Jeong Cho 1998
		All materials been delivered and allocated?	Jeong Cho 1998
	Labor and equipment	Work package scheduled?	Jeong Cho 1998
		Required laborers available for specific duration?	Jeong Cho 1998
		Required equipment available for specific duration?	Jeong Cho 1998
	Prerequisite work	All prerequisite physical work been completed?	Jeong Cho 1998
		All work areas been cleared?	Jeong Cho 1998
	Project scope statement		Norman, Brotherton 2008
	Resource breakdown structure		Norman, Brotherton 2008

Figure 31: List of data fields from the literature



KYP	Name	Name of activity	
	Project members	Name	
		Type (co-maker / supplier)	
	Planning	Duration	
		Start date	
		End date	
	Notes	Set notification	
		Notification message	
	Control list	Acceptance criteria	
		Optional picture	
	Documents	Documents	
	Profile	Company name	
		KVK	
		Adres (Street, number, postal code, city, country)	
		Website	
		Name, e-mail and phone number of director	
		Invoice e-mail	
	Contracts	Upload contract	
	Drawings	Upload drawing	
	Logbook	Write log (+ date)	

Figure 32: List of data fields from KYP



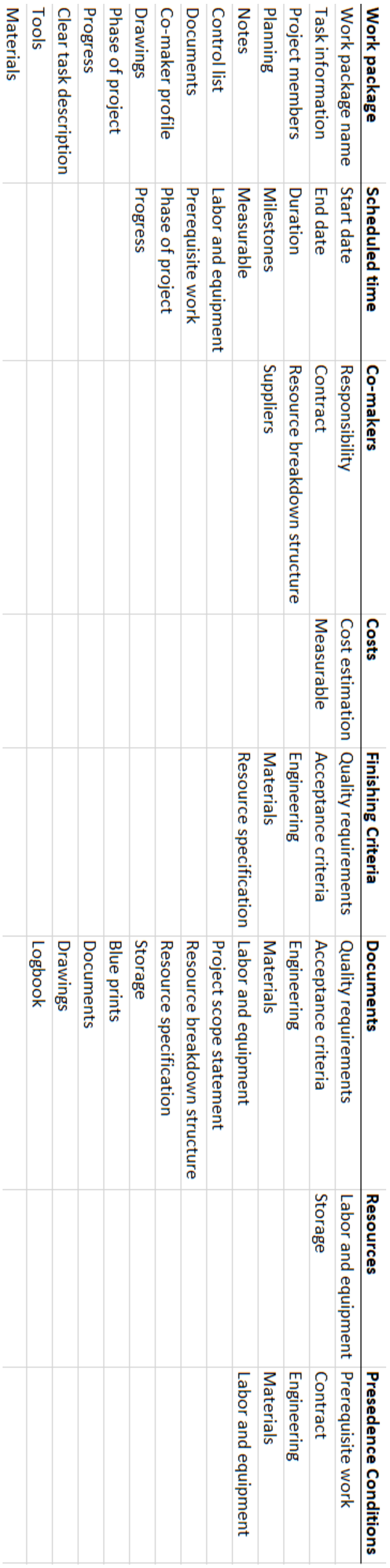
Stakeholder Analysis	Project leaders	Costs	
		Resource specification	
		Storage	
		Milestones	
		Phase of project	
		Progress (%)	
		Suppliers	
	Main contractors	Planning	
		Milestones	
		Acceptation criteria	
		Quality requirements	
		Blue prints	
		Clear task description	
	Foremen	Blue prints	
		Clear task description	
		Tools to be used	
		Materials to be worked with	
	Co-makers	Instructions	
		Blue prints	
		Quality requirements	
	Financial department	Product Ids	
		Price	
		Owner details	
	Planners	Task ID's	
		Start date	
		End date	
		Deadlines	
		Milestones	
	IT staff	-	
	Process manager	-	

Figure 33: List of data fields from the stakeholder analysis

Appendix I Categorization of data fields

After creating the list of data fields that were extracted from the different sources, we put the data fields in categories. On one hand we want to use as few categories as possible to prevent the model from becoming too large, but on the other hand there should be enough categories to assign every data field to a category that represents the underlying data field well.

The division in figure **??**, is the final division of data fields amongst the categories chosen. The categories cover the following topics:



Work package	Scheduled time	Co-makers	Costs	Finishing Criteria	Documents	Resources	Presedence Conditions
Work package name	Start date	Responsibility	Cost estimation	Quality requirements	Quality requirements	Labor and equipment	Prerequisite work
Task information	End date	Contract	Measurable	Acceptance criteria	Acceptance criteria	Storage	Contract
Project members	Duration	Resource breakdown structure		Engineering	Engineering		Engineering
Planning	Milestones	Suppliers		Materials	Materials		Materials
Notes	Measurable			Resource specification	Labor and equipment		Labor and equipment
Control list	Labor and equipment				Project scope statement		
Documents	Prerequisite work				Resource breakdown structure		
Co-maker profile	Phase of project				Resource specification		
Drawings	Progress				Storage		
Phase of project					Blue prints		
Progress					Documents		
Clear task description					Drawings		
Tools					Logbook		
Materials							

Figure 34: List of data fields from the literature