Reflections on estimating

The effects of project complexity and the use of BIM on the estimating process

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Abstract

Companies are starting to use Building Information Models (BIMs) for cost estimation purposes. This BIM-based estimating enables estimators to quickly and accurately extract quantities and estimate construction costs, potentially leading to a better estimate. In projects that are more complex however, acquiring an accurate estimate requires more effort, because complexity features influence the process and increase uncertainty and the chance of making mistakes. Furthermore, the use of BIM also influences the estimating process because the BIM determines quantities extracted and has a direct link to corresponding costs. This changes the ways estimators normally would estimate construction costs.

To explore the effects of project complexity and the use of BIM on the estimating process, I conducted three case studies, all concerning parking structure projects. The first case concerned a non-complex parking structure project to gain insight in the traditional estimating process. In the second case, I studied the effects of project complexity in a case concerning a complex project. In the last case study, I studied a BIM-based estimating process in a non-complex project to gain insight in the effect of the use of BIM.

The main effect of an increase of project complexity is the increase in difficulty to acquire or calculate proper quantities. Estimators react to this, by putting in more effort, or to add extra margins in the estimate. As for the effects of the use of BIM, it becomes clear that estimators and modelers have to coordinate their work upfront, to create a proper BIM that can produce all necessary quantities, and to align that BIM with corresponding recipes.

By addressing these effects, this research contributes to a better understanding of estimating and the effects of project complexity and the use of BIM. In turn, this can contribute to a better understanding of BIM-based estimating in complex projects.

Acknowledgements

This thesis would not have been possible without the help of several people. First, I would like to thank my university advisor, Timo Hartmann, who really helped me in doing, and learning to do research. I would also like to thank my company advisors Arjen Adriaanse and Kees Vermeij for their insights and the interesting discussions throughout my research period. Special thanks go to Baktiar Saeed, whom I closely worked with during most of my research period.

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1. Introduction

The use of building information models (BIMs) is evolving as an important tool in the build environment and estimators are starting to use BIM more often as a basis for construction cost estimation.
Estimators use BIM for cost estimation because by using BIM, they are able to produce quick and accurate quantities used to calculate construction costs. This more automated process can greatly shorten the otherwise labor intensive work of manual extracting those quantities from 2D drawings. Therefore, the use of BIM has the potential to, greatly improve the estimation process, since the ability to achieve the required estimate at minimal cost (and effort), is one of the most important keys to a successful estimate (Halpin, D.W., 2006, p223).

In traditional estimating, estimators have various ways and methods to acquire an estimate. In BIM-based estimating, the BIM directly links to corresponding costs and estimators are less able to use personal methods to estimate. Next to this, in more complex projects (e.g. non-modular parking structures), BIM-based cost estimation is not as quickly and automated as mentioned above. This is because estimators still have to conduct many manual adjustments and calculations for specific project conditions. This means greater effort is required to estimate accurately, especially in projects that are more complex. To improve the BIM-based cost estimating process, it first is important to have a clear insight in traditional and BIM-based estimating processes, and the influence of project complexity. To gain this insight, I have conducted a case study research with the following central research question:

What are the effects of project complexity and the use of BIM on the estimating process?

To answer this question, I have studied three cases concerning parking structure projects. First, I studied a non-complex, and a complex project to gain insight in het traditional estimating process and the effects of project complexity. In the last case, I studied a non-complex project with BIM-based estimating. By analyzing these cases and comparing them to each other, I was able to answer the main research question. Doing so, this research contributes to a better understanding of estimating processes and the effects of project complexity and the use of BIM. In turn, this can contribute to further research on BIM-based estimating in complex projects and support companies in integrating BIM in estimating processes.

This thesis continues with the chapter that summarizes the theory about cost estimation, project complexity, and the use of BIM in estimating processes. The next chapter presents the research question and method.
Chapter 4 presents in case analyses resulting from the case study research. In chapter 5, I will cross case analyze the three cases and make my conclusions on the effects of project complexity and the use of BIM. This chapter ends with a discussion about my findings, practical recommendations, and recommendations for further research. At the end of this thesis, I will address the theoretical and practical contributions of my research.

2. Theoretical Context

This chapter summarizes the theoretical point of departure. First, I will describe the estimating process in general. Second, I will shortly discuss project complexity features and their effect on the estimating process. Third, I will discuss the use of BIM in estimating processes. At the end of this chapter, I will address these three topics together and show how my research can contribute to these theories.

2.1 Cost estimation processes

Estimation is the process of looking into the future and trying to predict project costs and resource requirements (Halpin, D.W., 2006) Estimating is a vital part of the success of a project since the estimate is the basis for the contractor's bid and plays important role in the profitability of a project. According to Dysert (2004, p 9.1), further uses of estimates are:

- determining the economic feasibility of a project;
- evaluating between project alternatives;
- establishing the project budget;
- providing a basis for project cost and schedule control.

According to Halpin (2006, p208), estimators generally take certain steps in developing an estimate:

1. Break the project into cost centers.
2. Estimate the quantities required for cost centers that represent physical end items. For physical systems, this is commonly called the quantity takeoff.
3. Price out the individual quantities determined in step 2 using historical data, vendor quotations, supplier catalogs, and other pricing information.
4. Calculate the total price for each cost center by multiplying the required quantity by the unit price.
5. Add profit, overhead, risks, etc.

Cost centers result from estimators dividing the project in subdivisions for cost estimation purposes. Halping (2006) cites Neil (1982) who defines a cost center as follows:

> *A cost center is a well-defined scope of work that usually terminates in a deliverable product. Each center may vary in size, but must be a measurable and controllable unit of work to be performed. It also must be identifiable in a numerical accounting system in order to permit capture of both budgeted an actual performance information.*

By dividing the project into different cost centers, estimators form a work breakdown structure (WBS) to structure and control information. A WBS is especially useful in projects that are more complex because on such projects, the need for such a control and information structure is much greater.

The next step in developing an estimate is the estimation of the required quantities for cost centers (quantity takeoff). Quantity takeoff is the process of quantifying the size of each cost center. In traditional estimates, estimators perform a detailed examination of 2D drawings of the design to count the number of each item appearing in those drawings (Dysert, L.R., 2004, p 9.17). When estimators complete the count, they often summarize this in the WBS and start on pricing out the quantities.

Halpin (2006) states that estimators frequently use two methods. This is (1) unit pricing and (2) resource enumeration.

Estimators commonly use the unit pricing method for standard projects that are easy to estimate. Estimators use 'cost per unit' price from company records and apply this with necessary corrections

(e.g. for special site conditions). For example, an estimator may determine the cost of a wall by multiplying the area of the wall (in square meters) with the cost per unit (also in square meters) for similar walls.
The resource enumeration method has a different approach to determining the estimated cost. Estimators mostly use it in cases where there are unique or special design features. In the enumeration method, estimators break down the cost center into smaller sub features (Halpin, D.W., 2006). The estimator continues by assigning resource groups to these sub features. This allows estimators to adjust certain aspects of the recourses needed (e.g. working rate, production level) specifically for the element being estimated. This enables estimators, to make more detailed adjustments during resource enumeration. The way estimators adjust specific elements, is very personal and estimators have their own preferences (Staub-French et al., 2003).
The estimating method that estimators prefer, depends on many aspects (Dysert, L.R., 2004, p 9.5), such as

- the end use of the estimate,
- the estimating tools (e.g. software),
- the available data,
- the level of project definition/information, and
- the level of project complexity.

I describe the concept of project complexity in more detail in the next subsection.

2.2 Complexity of projects

The level of complexity of an activity or project is a function of three features (Maylor, H., 2003):

- *Organizational complexity* – the number of people, departments, organizations etc. that are involved,
- *Resource complexity* – the volume of resources involved often assessed through the budget of the project, and
- *Technical complexity* – the level of innovation involved in the product or the project process, or novelty of interfaces between different parts of that process or product.

These features influence cost estimation. Organizational complexity can lead to a loss of information, because communicating becomes more difficult when more people are involved. The information that is lost can sometimes be essential for acquiring an estimate. Organizational complexity can also mean that estimators work simultaneously on the same project. In this case, estimators or managers need to put more effort into coordinating this simultaneous work.
Resource complexity means that the total amount of work needed to estimate increases, which also increases the chance of making mistakes.
Technical complexity means that estimators will have to make more manual adjustment to acquire an accurate estimate. Next to this, in projects that are more complex are a lot more design changes. Depending on the sort of design changes, the estimator has to re-estimate the complete project or parts of it.

In general, two issues influence estimating activities on more complex projects. First, there is a higher demand for coordination and structure to prepare an estimate. Second, if complexity increases estimating will require more effort to acquire an estimate and the probability of making mistakes increases.

2.3 BIM-based cost estimation

A Building Information Model (BIM) is a virtual, computer-generated model that contains precise geometries and relevant data to support the construction, fabrication and the procurement activities needed to realize a building (Eastman, C. et al, 2008). As mentioned in the introduction, the use of BIM in the build environment is currently increasing and estimators are starting to use BIMs for certain reasons. This paragraph summarizes potential benefits of BIM for cost estimators and how estimators can use BIM for cost estimation. It further describes how BIM influences the estimating process. Last, I will discuss further research on cost estimation methods while using BIM.

The main benefit of BIM for cost estimation is the field of quantity takeoff. Estimators can extract quantities from the BIM for cost estimation using software applications. A BIM can support estimators in every design phase (Senate Properties, 2007). In early project (or design) stages, the BIM can produce quantities like volume and total area. These quantities may produce accurate enough estimates (e.g. by linking total volume of the building to a cost per cubic meter). Later on, as the model is more detailed, it is possible to extract detailed quantities of each building element (beams, columns, floors etc.) of the model. These quantities may form the basis for more accurate estimates, necessary in later project stages. Off course, a BIM can also provide important insight as the estimator can analyze the design in different ways.
It is possible to quickly extract detailed quantities directly from a BIM. Applications using BIM provide capabilities for extracting counts of components, area and volume of spaces, material quantities, and to report these in various schedules (Eastman, C. et al, 2008, p219). These quantities are suitable for cost estimation. It is clear that this more automated approach for quantity takeoff can greatly reduce the laborious task of manually extraction of these quantities from 2D drawings (Eastman, C. et al, 2008, p219). It is also possible to automatically link this quantity takeoff to estimating software.

To leverage on these potential advantages, the use of BIM for cost estimation also has three consequences for estimators. First, estimators need to align the estimating data (e.g. price catalogs) and the quantities extracted from the BIM. Quantities extracted from a BIM may be different from the quantities the estimator would traditionally extract. This is because traditionally estimators use various personal means to extract quantities and later estimate construction costs. Second, when the use of BIM in cost estimation results in the saving of time estimators may chose to use this time for optimization of other aspects (alignment of subcontractors, search for better/cheaper suppliers, etc.). Third, according to Eastman et al (2008), current BIM software is unable to identify specific conditions such as unusual wall or unique designs conditions. Because of this, estimators have to find a way to account for these conditions in BIM-based estimating. Where estimators would have various personal ways of accounting for special conditions in traditional estimating, they are now limited because the basis of the estimate are the quantities extracted from the BIM.
S. Staub-French, et al. (2003) confronted these kinds of problems and formulized a customization process. They presented an ontology that relates features (like intersections or wall curvature) of a BIM to construction activities and associated construction resources (materials, labor, equipment, and subcontractors) to calculate costs. In fact, the research shows a way to automate (and speed up) the resource enumeration method by making estimating methods of estimators more transparent and computer-interpretable. However, it does not address how to cope with more complex projects with unique conditions. Staub-French et al. (2003) state that they excluded several aspects in their research such as dissimilarity of components (e.g. a lot of differ wall types) and difficult project conditions (e.g. site conditions). These kinds of aspects are more common in complex projects.

2.4 Conclusions and theory for research

The previous sections have described the cost estimating process as a whole and the various parts of the process. Focusing on the various parts of the process, I showed that an estimator follows certain

steps and that there are different methods used in these steps. As a whole, the estimation process serves several purposes and has several related processes.
The complexity of projects is a function of three features that have an effect on the estimation process. The use of BIM has two benefits. First, it can automatically produce accurate quantities, used for cost estimation. Second, it is possible to create an 'active' link between the design and corresponding costs so when the design changes, so will the estimate costs. When estimators use BIM in cost estimation, this also influences the estimating process. Table 1 summarizes the influences of project complexity and the use of BIM.

Table 1: ***Influences of project complexity and the use of BIM***

	Project complexity	Use of BIM
Influence	▪ Higher demand for coordination and structure. ▪ Higher effort required to estimate and probability of making mistakes increases.	▪ Quick extraction of quantities is possible. ▪ Direct link between BIM and corresponding costs. ▪ Estimators are less able to use personal preferred methods to extract quantities, since the BIM determines quantities extracted.

Since the use of BIM in estimating processes is relative new, there is a shortage of knowledge about the role of complexity in BIM-based estimating processes. To explore how project complexity influences the process of BIM-based estimating, it is important to first, understand (1) estimation processes in complex (non-modular structures) projects and (2) BIM-based cost estimation.
Since both project complexity and the use of BIM influence the estimating process, it will be important to review the entire estimation process in different conditions.

3. Research Method

The goal of this research is to explore the effects of project complexity and the use of BIM on the estimating process, and search for important aspects of successful BIM-based estimating.

Linked to the research goal is the main research question:
What are the effects of project complexity and the use of BIM on the estimating process?

From the main research question, I derived several sub questions.

1. What are the effects of project complexity in traditional estimating processes with respect to process structure and estimating methods?
2. What are the differences between traditional and BIM-based estimating?
3. What are important aspects of BIM-based estimating?

To answer the research question, I conducted a case study research (Eisenhart, 1989). In line with suggestions made by Verschuren & Doorewaard (2007), I studied cases in a certain order. After studying the first case, I decided which and what case would be next. This way, I was able to choose the best suitable case to achieve my research objective and answering the sub questions.

In total, I studied three cases, all concerning parking structure projects. Differences between the three cases were the level of complexity and whether or not estimators used a BIM to estimate. By

choosing only parking structure projects specifically, it was easier to compare the cases to each other.
In all cases, I have studied the estimating process (including related company processes), using documentation about the case, such as project definitions, drawings used for estimating, and results of the estimate. I also conducted informal interviews with people involved with the estimating process. Last, I was an observer of day-to-day practice at the company, Ballast Nedam. Altogether, this enabled me to gain integrated knowledge about the estimating process. I have structured my findings in a uniform matter. In each case, I described the estimating process from start (input) to finish (the estimate) focusing on process steps, involved people, and estimating methods. I also addressed project specific aspects to analyze complexity features. By doing this, I was able to list similarities and differences between different cases more easily. According to Eisenhardt (1989), this led to a more sophisticated understanding of the processes I studied.

3.1 About the company, Ballast Nedam (division Infra)

I performed my research at Ballast Nedam, more specifically their division of infrastructure (Infra). This division just started using BIM to support cost estimation and the first kind of project where it used BIM to support cost estimating was a modular parking structure project.
In general, Ballast Nedam has two different kinds of parking structure projects, modular and non-modular. Ballast Nedam developed a modular parking structure that is easy to construct and dismantle so Ballast Nedam can use parts of the project on other projects. Although many different configurations are possible, the modular parking garage consists out of standard columns and standard floors. The choice to use standard elements is the main difference that makes modular parking structure projects less complex than non-modular projects.
Altogether, Ballast Nedam was a suitable company to conduct my research. This is because I was able to study three distinctive cases, and could compare these to one another to gain knowledge about estimating processes, and the effects of project complexity and the use of BIM on that process.

The first case concerned a non-complex, modular parking structure project with traditional estimation. This was a good starting point to understand the estimating process. It also formed a baseline for case comparison. The second case study concerned a more complex, non-modular project, again with traditional estimation. By comparing this case to the first case, I was able to understand the effects of project complexity. The third case concerned the same project as the first case, only this time the estimator based the estimate upon a BIM. By comparing this case to the first case, I was able to understand the effects of the use of BIM for cost estimating.

During the case study research, there were a number of meetings about the integration of BIM in the cost estimating process. Present at those meeting were estimators, modelers, supervisors, and consultants. I joined these meetings and collected documentation resulting from those and previous meetings. More importantly, this was a great way to verify my findings by discussion them with the persons involved.

4. In case analyses

In this chapter, I will discuss the in case analyses, resulting from my case-study research. First, I will address the context of parking structure projects. In the rest of this chapter, I will discuss the three case studies. There, I will first address traditional estimating in a modular parking structure project (case 1). Next, I will address traditional estimating in a more complex, non-modular project (case 2). Last, I will address the third case study where I discuss the BIM-based estimating process.

4.1 Parking structures

In most cases, the shape and form of parking structures are determined by:

- Available area
- The number of parking places that the parking structure should facilitate
- Maximum tolerable height (usually in number of parking levels)
- Regulation and guidelines
- Accessibility and connection to roads

Altogether, parking structures are similar to one another. Construction is mostly done with prefabricates elements like steel or concrete columns and prefabricated concrete floors. This also reflects on possible design alternatives. Design alternatives mostly only concern a specific part of the project and a specific part of the estimate. Examples of these alternatives are foundation types or exterior facades.

4.2 Case 1: The traditional estimating process in a modular parking structure project

The first case study concerned a modular parking structure. As mentioned earlier, the modular parking garage consists of standard elements, such as columns and floors.

Figure 1: ***A picture of a modular parking structure project.***

From the estimating perspective, modular parking structures are simple projects. Already at the start of a project, there is knowledge about the structure. The estimator easily extracted the necessary quantities, by simply counting the number of elements and move on to creating the estimate. Because of project simplicity, there was almost no risk of miscalculations or omissions. The estimator further needed little time to assess the project, since most things were already clear.

In the first case, the estimator created a very detailed estimate and did this to increase accuracy and reusability. Because of the project similarity, the estimator could use old estimates. This way, the estimator could create a very detailed estimate with little effort. This detailed estimate is beneficial because it is easier to prepare a project budget and to perform cost control later on.
Altogether, the estimator could very quickly establish an accurate estimate, based on company records. Furthermore, there was sufficient time for preparing purchase orders and price optimization

4.2.1 Estimating process

Figure 2 shows this estimating process, consisting out of four parts. I will elaborate on every one of these parts separately.

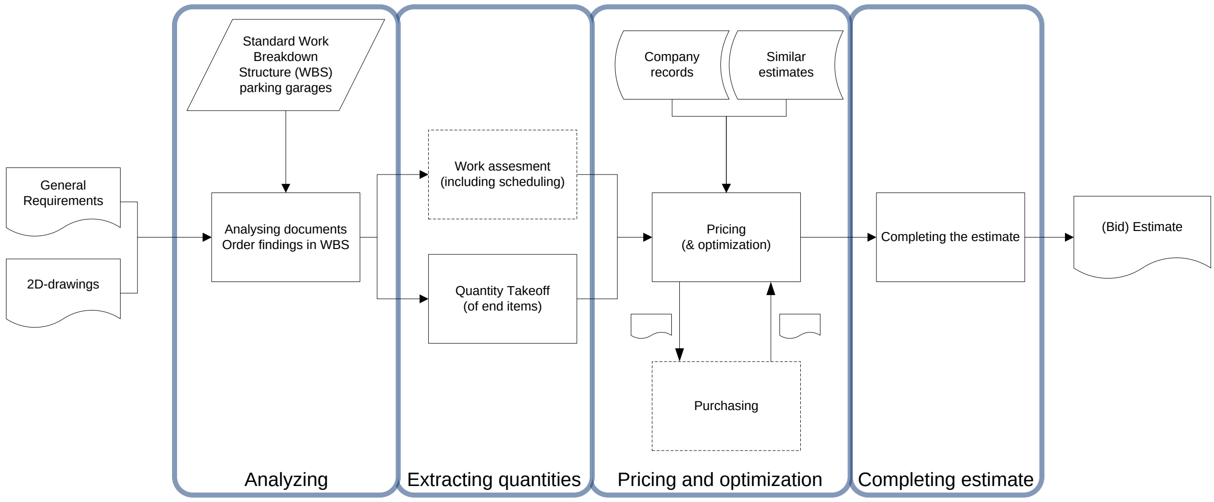

Figure 2: The estimating process, which consists out of four parts (analyzing, extracting quantities, pricing and completing the estimate). Dashed boxes concern processes where other persons may be responsible.

4.2.2 Analyzing

In the case of the first case study, the input consisted out of documents containing general requirements and the design (2D drawings). Also included was documentation on surroundings, ground properties and fire rating.

The first step of the estimator was to analyze the input. The estimator went through the documents and summed up all aspects that incurred costs. The estimator used a WBS to order those costs.

In this case, the estimator was responsible of establishing the buildup of the WBS and corresponding coding. The estimator divided the project on several levels. On the highest level was the end product, in this case a modular parking structure. The second and third level consisted out of a main division and sub-division. The fourth and final level consisted out of objects. By now, the estimator had established a System Breakdown Structure (SBS) which formed the basis for the WBS. The main difference between a SBS and a WBS is that the WBS consists out of activities (to construct objects) instead of objects. To perform these activities, resources such as labor, materials, equipment and subcontractors, are required.

Figure 3 shows an example of the buildup of the WBS.

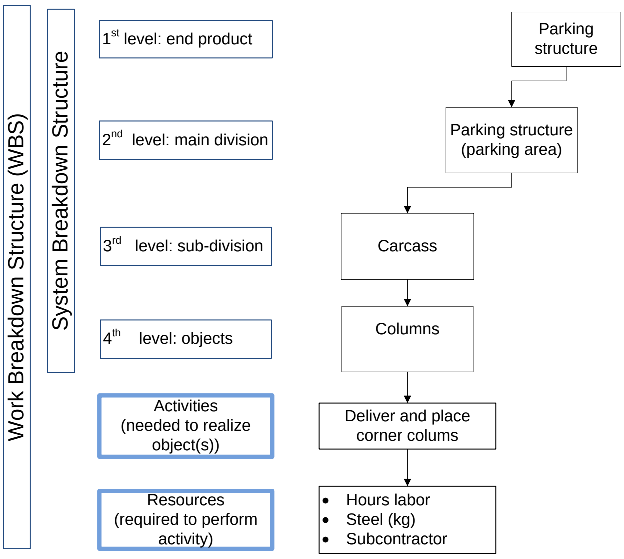

Figure 3: *Example of the buildup of the WBS used in the first case*.

In the case of parking structures, Ballast Nedam Infra already prepared a standard WBS. People throughout Ballast Nedam Infra use this WBS and the estimator structured the estimate in line with this WBS. Along with the WBS, each object, activity and resource in a project, has a unique code. This makes costs traceable, because people such as purchasers also used the same WBS-code. Figure 4 shows this standard WBS and code.

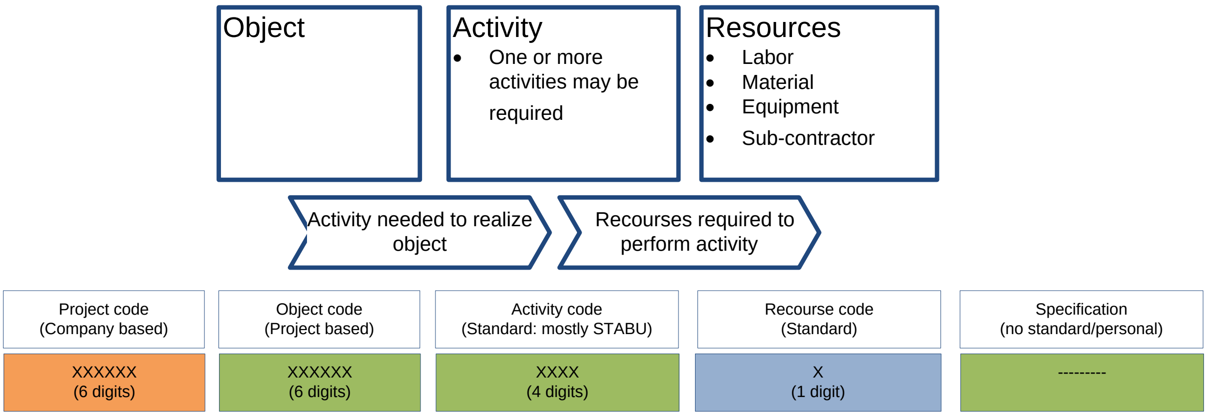

Figure 4: Corresponding with the work breakdown structure, a numerical code is given is to keep objects, activities and resources traceable. The estimator can give further specifications.

4.2.3 Extracting quantities

The second part of the estimating process concerned the extraction of quantities. This part consists out of two different processes. I named these 'quantity takeoff' and 'work assessment'.

Quantity takeoff

For physical items (e.g. concrete floors, stair casings), the estimator had to manually extract necessary quantities from project documentation such as drawings or general requirements. The estimator did this quite fast for most parts of the project, by simply counting each item appearing on the drawings. More difficult to extract were the number and lengths of foundation piles. Here, the estimator also had to examine ground properties to determine what kind of piles the contractor should use for construction.

Work assessment

Next to physical items, the estimator also had to account for other aspects that incur a cost, such as site conditions, duration of construction, work schedule and working methods. This is because these conditions influence things such as required equipment, total hours of labor, special building permits, which are costs that estimators should account for. A good example of this in this case, was that the estimator had to determine how many prefabricated floors the contractor would be able to place per hour. This process requires engineering and project management skills and experience. In the first case study, the estimator also fulfilled the role of creating a schedule. Later on, a scheduler uses the input of the estimator and finishes a schedule, adding activities that the estimator did not account for. That main difference between the schedules of the estimator and the scheduler is that the estimator only accounted for activities that incurred costs and the scheduler focused on how much time is required for each activity and in what order those activities should take place. This schedule was also a part of the tender documents.

4.2.4 Pricing

After extracting the required quantities, the estimator followed the process by pricing these quantities.

To acquire a price, the estimator

- used company records/catalogs or previous estimates (internal), or

- requested prices from sub-contractors or suppliers (external).

In this project, the estimator first used company records to establish a first estimate and simultaneously started on requesting prices (purchase orders) from sub-contractors and suppliers, especially for main cost items. In this case study, this concluded foundation (piles), columns, floors, staircases, etc. A purchaser, responsible for the purchasing of materials and subcontractors, had the task to acquire these prices, which took up 3-7 days. The estimator requested these prices as soon as possible (after quantity takeoff). Later on, the estimator compared the costs in the first estimate to the requested prices. This was a very important part of estimating because this offered two benefits. In the first place, the estimator was able to check whether the used company records in the first 'basic' estimate were correct. Second, the estimator was able to find the cheapest sub-contractors and suppliers to decrease overall project cost, which improved the chance to win the tender for the job, or improve project profitability.
After requesting the prices, the estimator started with creating the estimate. To do this, the estimator used previous estimates of other modular parking structure projects, and company records. In the studied case, the estimator used a cost per unit as the estimating method. In the case of parking structures, the estimator elaborated on these prices by adding a text to indicate thing such as work rate and composition of work crew. This made clear what costs the estimator accounted for. Benefits of this are:

- Better insight in costs (for estimate control)
  By elaborating on costs, it was easier for supervisors to understand what the estimator accounted for and in what way.
- Higher accuracy,
  Because the estimator elaborated on costs in previous modular projects, it was now possible to adjust specific parts of those costs better, such as the work rate for placing floors.
- Higher probability of winning job tenders
  In discussions with people such as the estimator and tender manager, it came forward that a more specific document looks more reliable.

4.2.5 Completing the estimate

This part consisted out of finishing the estimate. After determining the estimated cost price, the estimator continued by accounting for contingencies and profit margin. In this case, there were basic percentages taken into account because the estimator was certain that the estimate was accurate enough. Last, the estimator, and other involved people such as supervisors/managers reserved a few days for meetings for estimate control and tender preparation. Supervisors first paid attention to the overall estimated costs by comparing those costs to other projects and company records. Second, they checked specific elements of the estimate, such as the assumed work rate for placing prefabricated floor elements.

The result was the bid estimate, which together with the schedule and the design, was a part of the tender documents.

4.3 Case 2: Non-modular parking structure (increased project complexity)

In the second case study, I studied a more complex project to gain knowledge about the effect of project complexity on the estimating process. This case concerned a project that was much larger; the project budget was six times higher than the first case. Technical difficulties were an intersection with a metro line and a special access road.

Furthermore, this project concerned a Design & Construct contract so the contractor was also responsible for the design of the parking structure. In this case, an architect was responsible for delivering a design and yet another company was responsible for the constructional design of the structure. Together, they had to deliver the information necessary to determine required quantities to realize the design. This was a major difference with respect to the first case study where just one party, Ballast Nedam, was involved. With regard to the first case study, there was an increase in all three features of complexity (organizational, resource, and technical). From these three features, organizational complexity was the most dominant. This increase in (organizational) complexity was noticeable throughout the estimating process, especially in the first three parts of the traditional estimating process (see section 4.2). I will elaborate in more detail for each of these three parts.

Figure 5: ***The second case study concerned a non-modular and more complex parking structure project. This image shows the architectural design of the five levels containing parking structure with intersecting metro line.***

4.3.1 Analyzing

At the start of estimating process, there was not yet a detailed design ready. Specific drawings of parts of the structure, such as the special access road were not clear. Most important, a clear overview of the design was not available. The estimator frequently had to put effort in communicating with other parties to discuss things such as, design changes, which drawing were valid, and how people had extracted quantities. Altogether, this meant an increase in organizational complexity. This was the most problematic issue in creating a good estimate and the amount of effort required to estimate.

4.3.2 Extracting quantities

The organizational complexity also reflected on the way the estimator had to extract quantities. First, this complexity caused delay in acquiring the required quantities, because it took several days before the designer send accurate drawings that would not change anymore. This delay shortened the time available for pricing and optimization because of fixed tender deadlines. Second, this complexity increased the chance of making mistakes or overlooking parts. In this case, the estimator had to put extensive effort in acquiring quantities. Often things, such as the steel structure and shape of facades changed so the estimator had to re-estimate these parts of the project. Because of unclear designs, a good overview of the projects was not available. Often, the company responsibly for constructional designs sent only hand drawn sketches. For the facades, the estimator had to make an educated guess in extracting quantities.
Resource complexity was also involved due to the size of the project. Project costs where six times higher compared to the first case study. Due to this, it was more likely that the estimator made mistakes in determining the right quantities.

4.3.3 Pricing

According to the estimator involved, there were only a few days available for cost optimization. The estimator only requested prices for electric installations and concrete elements because the estimator could extract these quantities more quickly. Compared to the first case, the estimator requested relative few prices, simply because most external companies would not have the time to make a proper offer. Altogether, this meant that the estimator based this estimate more upon company records than on requested prices from sub-contractors and suppliers.

In the case that the estimator was not sure, whether or not the quantities were correct, the estimator adjusted quantities or the cost per unit price to account for those uncertainties. For steel quantities, the estimator rounded up the number and increased the cost per unit (kg). In the second case study, the estimator considered extra margins quite frequently, in contrast to the first case study.

4.4 Case 3: BIM-based cost estimating process in a modular parking structure project

The third case study concerned a pilot project for BIM-based cost estimating. For this pilot, the company selected a modular parking structure, because these kinds of projects are simple and easy to understand and model. This pilot concluded the same project as I had studied earlier (case 1).

Based on this pilot project and discussions with people involved, I have visualized the BIM-based estimating process (see Figure 6). I will discuss the specific parts of this process and elaborate on the benefits and problems of BIM-based estimating, resulting from this pilot project.

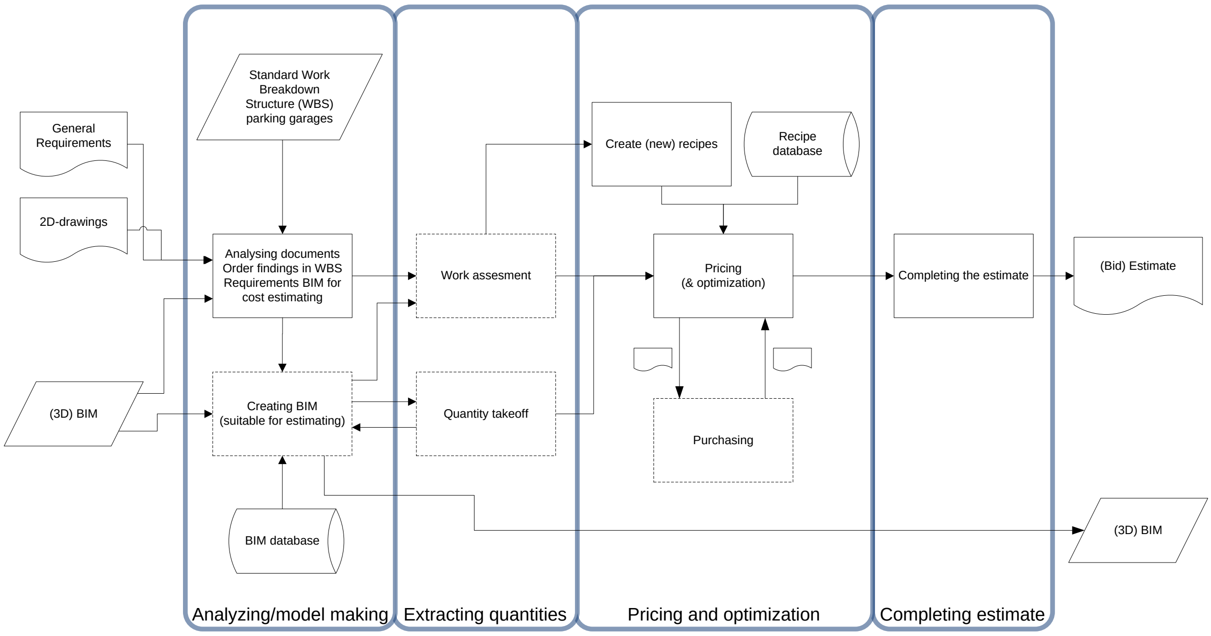

Figure 6: ***BIM-based cost estimating process***

As before, the process consists out of four parts. However, there are some differences, mainly because a new role appears in the process, the (3D) modeler. This also increased the organizational complexity.

4.4.1 Start

The input of this BIM-based estimating process was the same as in the first case study and concerned starting documents such as 2D drawings and general requirements.

4.4.2 Analyzing

The estimator started by analyzing general requirement, 2D drawing, and other possible documentation. As before, the estimator established a WBS for the specific project, which was the same WBS as in the first project. At the same time, the modeler analyzed the drawings and evaluated how to model the design easily and correctly. In this case, the modeler could easily create a model because for the most part, the model consisted out of four different types of floors and six different kinds of columns.

For acquiring a proper estimate, the estimator needed to determine how detailed the BIM needed to be, and what quantities needed to be extractable from the BIM. For the estimate, different kinds of quantities were required and were not always extractable from the BIM. One example of such a quantity was the number of parking places on each floor element. To be able to extract that quantity, the modeler needed to make sure this information was extractable for example, by adding shared parameters into model elements.
It further was important that the estimator had knowledge about what quantities are extracted. For instance, the estimator had to know that the lengths of each column extracted from the BIM, were the same lengths, as the estimator would normally use.
Last, the estimator and modeler had to discuss the project specific WBS. This was important because the estimate needed to have the same buildup as the project WBS. They did this because using this WBS makes the estimate usable for cost control. Altogether, this meant that the modeler had to use the WBS coding in the BIM.

So, the estimator and modeler had to:

- Communicate about the level op detail of the model (what should be modelled).
  In this case, the estimator and modeler decided to exclude foundation piles and electical wiring. For electrical wiring, the estimator would normally use the total area of the structure and a cost per unit (m^2) to account for wiring. To add this into te model, the modeler had to model a basis floor to be able to extract this area.
- Communicate WBS (discussing possible overlap).
  Some steel columns could be regarded as part of main parking structure or as part of stair casings. To prefend that columns would be accounted for twice, the estimator decided to just account it as part of the structure and that those columns only should have the WBS-code that corresponds with the structure.
- Communicate what the model should produce (adding properties/parameters).
  The modeler added an extra parameter to floor elements so the exact number of parking places could be extracted.
- Coordinate the (digital) extraction of the right quantities for estimating with the modeler.
  Because the estimator dit not have software to model the BIM (Revit Structure 2010), the modeler was responsible for extracting the quantities. The estimator did have to check whether this export of data was succesfull.

In discussions with people involved, one of the most important parts of BIM-based estimating was the communication between the estimator and the modeler. The estimator really had to evaluate the design/model with the end in mind and had to know what kind of estimate had to be achieved and what the project specific requirements were for a proper BIM.
An important starting point of this pilot was that the BIM-based estimating process had to produce the same estimate as the traditional process. It had to produce the same total costs and be as detailed as the traditional estimate would be. A second starting point was that the BIM-based estimate had the same WBS-structure and code as the traditional estimate.

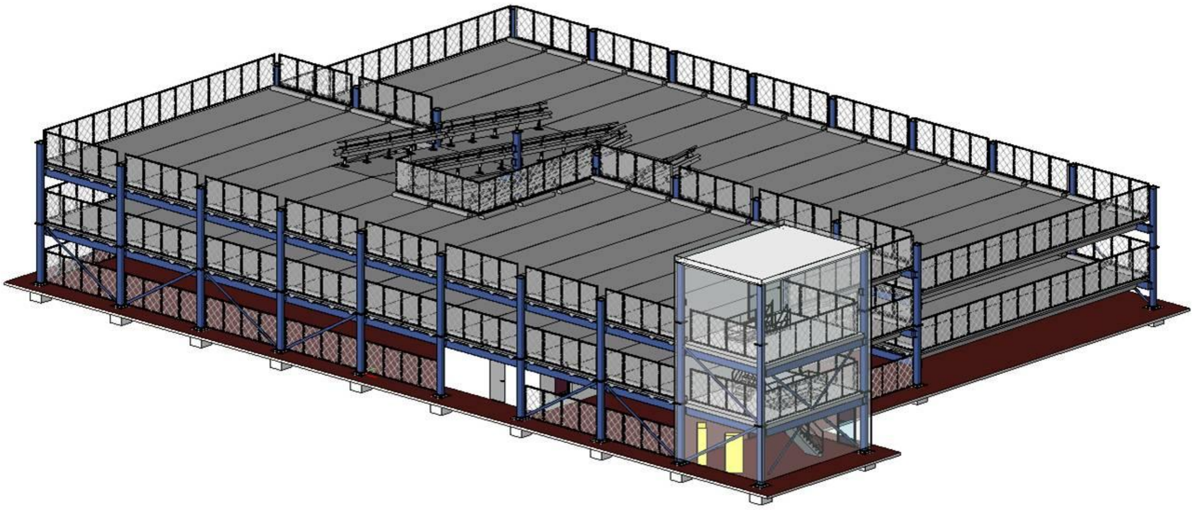

Figure 7: ***A BIM of a modular parking structure, in this case created using Revit Structure 2010 (Autodesk).***

4.4.3 Extracting quantities

As in the traditional process, this part consisted out of 'work preparation' and 'quantity takeoff'. The estimator still did work assessment in a traditional manner, based on 2D-drawings and project documentation. In the first case, the estimator would adjust prices, based on that assessment. However, because this case concerned the same project as case 1, the estimator basically used the traditional estimate to prepare recipes.

The quantity takeoff was automatically generated from the BIM. The estimator used estimating software to link this 'bill of quantities' (automatically) to recipes that corresponded with prices. Here, the estimator had to check whether or not proper, and all necessary quantities were extracted. As mentioned before, the model first did not produce the total area of the structure and the modeler had to add this to the model. Other parts that the modeler had to add later were fences and railings. In the first case, the estimator would simply measure the outline of the structure and calculate these quantities. In this case, the BIM had to produce this quantity so the modeler had to add this to the model.

4.4.4 Pricing

Next to the quantities extracted from the BIM, also recipes were necessary to acquire an estimate. The estimator based these recipes on the estimate of case 1. In the first case, the estimator copied a similar previous estimate, adjusted it to the current project and fill in the new quantities that were extracted earlier. Now, the estimator first had to link resources to activities and link all activities in a recipe. Because this case concerned a pilot project, the estimator had to create all recipes. The estimator had to make these recipes parametric which means that the amount of resources, and therefore costs, would automatically change with changes in quantities (design changes).

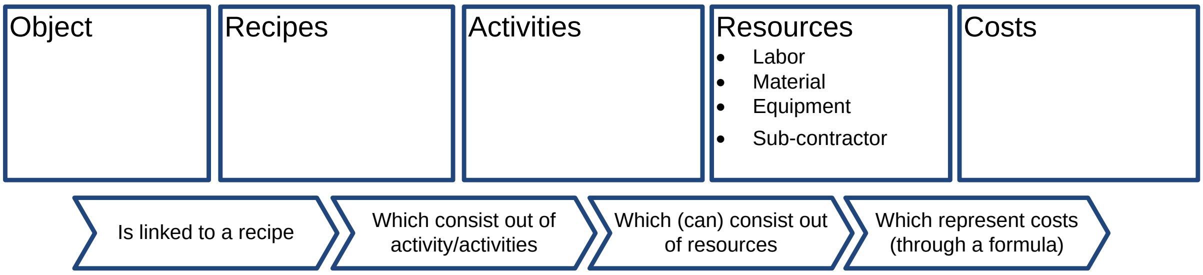

Figure 8: Visualization of how objects in a BIM correspond with costs. Recipes can be very detailed or more abstract. In this pilot project, the recipes were just as detailed as in the traditional estimate. The buildup of this recipe is the same as the WBS used throughout the company division.

Figure 8 shows the basic principle for relating objects of the model to costs, as it was in the third case study. Objects in the model had a WBS-code, and this code formed the link with recipes that had the same WBS-code. It was therefore also important that the modeler and estimator did not make any changes in this WBS-code without consulting with each other. For the most part, the estimate in this case was very detailed but there were exceptions where the estimator applied another principle. For the costs of electrical wiring and lighting, the estimator wanted to link the gross area of the structure directly to a special unit price (e.g. cost/m^2). This meant that de recipe itself represented costs, instead of representing costs via activities and resources.

Because this case was a pilot project for BIM-based estimating and did not involve a tender for a job, the estimator did not request any prices. However, I did discuss about what the estimator could do with those requested prices. Resulting from this discussion was that the estimator would have two options to integrate those prices in the estimate:

1. The estimator would build the requested prices into a recipe, keeping the recipe parametric.
2. The estimator would use the requested prices in the final estimate instead of the price that resulted from the initial BIM-based estimate. This can save time because the estimator does not have to change a specific recipe, which is more labor intensive, but does means that the estimate is no longer parametric.

4.4.5 Completing the estimate

At first, this part of the estimating process was the same as in the first case study. Supervisor still needed to be able to check certain aspects of the estimate quickly, as it would be in other projects. For supervisors, it was important that they could directly spot assumptions made by the estimator. In BIM-based estimates, these assumptions may be hidden inside parametric formulas. The best example of this was the working rate. This rate would normally be visible on the printout of the estimate but did not show on printouts of the BIM-based estimate because it was a part of formula.

The estimating software is able to check if all objects are linked to a recipe. Therefore, there is a certainty that all modeled objects, are in some way accounted for. This however, does not have to mean that all costs are accounted for since usually, not all cost sources are modeled.

The estimator accounted for costs in a BIM-based estimate when:

- the cost source is modeled as an object, or
- the cost source is accounted for in a recipe that is linked to modeled object.

An example would be lining on prefabricated concrete floors. The modeler could model the paint for this lining, or the estimator could take this into account as a factor in the recipe of the floors. Here, there was a choice about what the modeler should model and how the estimator would account for

costs. The estimator and the modeler needed to make that choice at the start of the process. Other examples of these kinds of choices were about adding railings and fences to the BIM.
Next to the (bid) estimate, this process also produced a BIM.

5. Findings

In the previous chapter, I described various aspects of the three cases studied. This chapter summarizes my finding and I will compare the different cases with each other. This enables me to extract important aspects of (BIM-based) estimating processes and estimating in projects that are more complex.

5.1 Case comparisons

5.1.1 Project control

Estimating is a part of the total company process and relates to the other aspects of the company process. In each case study, this was clearly visible because of the use of a (standard) WBS. The company used this WBS in different processes such as planning, estimating, and cost control. This relation with other company processes is an important aspect and companies should always consider this during discussions about BIM-based estimating processes. Especially the link between estimating, cost control and BIM is important.

5.1.2 Time and effort

Comparing case 1 and 2

Comparing case one to case two, there are two clear differences. First, the total time to acquire an estimate was greater in case two. A second and more interesting difference is the time that was available for pricing and optimization. As described earlier, analyzing documents and extracting quantities in the second case study was difficult and time consuming, mainly caused by organizational complexity. Because of fixed tender deadlines, this greatly limited the available time for pricing and optimization.

Comparing case 1 and 3

Comparing the traditional and BIM-based estimating process (case study 1 and 3); it was clear that the BIM-based estimating process was more time consuming than the traditional process. This was because the estimator first had to coordinate actions with the modeler. When this coordination finally was successful, the estimator could quickly extract quantities. This however, was also the case in traditional estimation process in case study one, because of a great deal of standardization in modular parking structure projects. In the modular projects, extracting quantities is relative easy and therefore, the quick extraction of quantities using a BIM did not result in real `benefit' with respect to time saving in the third case.

With respect to effort, there are also differences between traditional and BIM-based estimating that concern the estimator and the modeler.
For the estimator there was a shift of workload. Instead of manually calculating the required quantities, the estimator could do this more or less automatically using a BIM. The estimator did however, had to put extensive work in creating recipes. How much effort this work takes, depends on the project. In similar projects, acquiring the right recipes would be fairly simple. Another task the estimator has to perform is coordination of activities with the modeler involved.

Creating a BIM becomes a new part in the estimating process and the modeler is responsible for creating a suitable BIM for cost estimation. People could argue that, strictly speaking, creating a BIM is not a part of het cost estimating process and could just be regarded as process input. However, there are specific requirement for cost estimating using a BIM. Requirements that I encountered during the case study research were:

- Adding of WBS-code
  Without this code, recipes could not be linked to objects.
- Adding of extra parameters

In case 3, the model had to produce the number of parking places. Since this was not an extractable quantity, the modeler had to add this to the BIM as an extra parameter.

- Adding extra objects to the BIM
  The estimator needed the total area of the structure to account for electrical wiring and lighting. To do this, the modeler had to add an object that would produce this area and give it the corresponding WBS-code.

These activities, performed by the modeler should be regarded as part of the estimating process.

To summarize:
In the first two case studies, most labor intensive work was:

- manually extracting quantities (calculations), and
- coordination with external parties (depending on level of complexity of the project).

In the third case, with BIM-based estimating, this was:

- creating proper recipes,
- creating a proper BIM, and
- coordination between estimator and modeler.

5.2 Conclusions

5.2.1 The effect of project complexity on estimating

Based on the first two case studies, I was able to find the most important effects of complexity features on the estimating process. Each of the complexity features has a specific effect but from an estimating perspective, there were two major kinds of effects[1]:

- There is a shortage or obscurity of information needed for estimating.
- There is an increase in difficulties to calculate quantities, increasing changes of making mistakes.

Estimators reacted to these effects by:

- putting more effort into acquiring required data or information, or
- adding extra margins in the estimate such as increasing quantities, the cost per unit price, work rate, risk margins, etc. An estimator may account for uncertainties in many different ways and is therefore very personal.

5.2.2 The effect of BIM on estimating

At first, the BIM-based estimating process is very similar to the traditional process, since it follows the basic steps such as analyzing, extracting quantities, pricing and completing the estimate. The most visible change is the fact that a modeler is introduced into to process, which also increases organizational complexity.
Before it is possible to acquire a BIM-based estimate, it is of utmost importance to align the BIM and the project specific recipes. Furthermore, it is important that a BIM is able to produce the quantities that are required for estimating. This means that modelers and estimators have to coordinate their work of creating a proper BIM and suitable recipes for estimating. To coordinate this work properly, estimators have to know what kind of estimate they have to achieve. Coordination with the end in mind is essential. As is shown in section 5.1.2., there is a shift in workload where coordination of activities, creating of a proper BIM, and creating suitable recipes requires the most time and effort.

[1] In appendix A, a table is included where I analyzed the different complexity features by linking them to the most common errors in estimating according to Halpin (2006). Also mentioned in this table, are related features of BIM-based estimating.

Another important aspect of BIM-based estimating is the fact that there is a direct link between BIM and estimate. This does however, limits the various ways estimators can adjust recipes and costs. First, estimators were not able to adjust the quantities extracted directly. Second, estimators have to keep recipes parametric because only then, will costs automatically change when the design changes. Last, estimators have to make adjustments transparent especially because computer interoperability becomes more important in BIM-based estimating.

5.3 Recommendations

5.3.1 Practical recommendations to improve BIM-based estimating

As is shown earlier, there is a shift in workload. One way to improve the estimating process, is to reduce the effort it takes to estimate accurately using BIM. Companies can achieve this by structuring the coordination between modeler and estimator and between BIM and estimating recipes.

Ways of structuring the process would include:

- Standard Work Breakdown structure
  There use of a standard WBS in the studied cases was essential to estimate successfully and coordinate with the modeler. By using a standard WBS, estimators and modelers do not have to establish a WBS first, which can be time consuming.
- Standard levels of detail for modeling and estimating per project type.
  Standardizing levels of detail would mean that it is easier to create a BIM (knowledge of requirements) and have suitable recipes. This becomes more useful when there are multiple similar projects because in that case, recipes are reusable. Determining suitable levels of detail depends on various aspects such as the end goal of the estimate, project similarities, and efforts estimators and modelers have to make.
- Documenting information requirements.
  Along with agreement on a standard level, there should also be documentation about information requirements. This can support modelers and estimators in creating a proper BIM and estimate because it is clear what sort of information has to be extractable from the BIM.

These points of improvement enable modelers and estimators to work more independent and focus coordination on project specific parts. It also helps to make recipes and models more reusable reducing the need for adjusting recipes or creating new ones for other projects.

When we discuss these points of improvement in the context of parking structure projects, we first need to conclude that such projects are similar to one another. Estimates of these kinds of projects were very detailed in the studied cases. This makes tradeoffs about the level of detail in BIM-based estimating easier. In the case of parking structure projects, a high level of detail is recommended because this is fairly easy to achieve. Things like recipes are likely to be reusable in most cases. It also limits effort in other processes like cost control because a detailed estimate is already prepared (see section 4.2).

5.3.2 Recommendations for further research

During my research period, I had to limit my research in some ways. First, I was unable to study a fourth case that would concern a complex project with BIM-based estimating. By studying such a case, it would be able to study the effects of project complexity on BIM-based estimating and find ways to improve that process. Second, it was hard to determine all benefits and problems of 'normal' BIM-based estimating, because the third case study concerned a pilot project in BIM-based estimating. Third, I was unable to evaluate different way of creating or adjusting recipes, which may be an important factor in proper BIM-estimating. All this may be possible in the future when there is more experience with estimating using a BIM.

One important aspect to keep in mind is the influence of a BIM on the total project management. A BIM can serve multiple purposes and the use of BIM benefits things such as evaluating design alternatives and coordination between parties. In estimating, proper information such as proper drawings are essential and any obscurity can form a problem. It is very interesting to analyze the uses of a BIM for estimators further, because they might already be able to acquire a better estimate when they use a BIM in, an otherwise traditional, estimating process.
A last important aspect to consider is the fact that BIM-based estimation is not suitable to evaluate design alternatives quickly. This is because in BIM-based estimating, only differences in quantities are properly processed (Staub-French, S., Fischer, M., 2001). Ways to visualizing cost drivers in a BIM early design stages (evaluating of design alternatives) would be very useful to produce a final design earlier. This ultimately helps estimators and modelers to focus on just on one BIM and estimate, limiting the effort required to estimate.

6. Theoretical contributions

A key aspect of this research was to understand the entire estimating process in the different projects conditions. After conducting the three case studies, I was able to summarize the effects of projects complexity and the use of BIM on the estimating process. Therefore, this research adds to the general understanding of (BIM-based) estimating processes. Furthermore, it can contribute to further research on BIM-based estimating processes in projects that are more complex.

7. Practical implications

As BIM-based estimating is relative new in the build environment, this research can play an important role in integrating BIM-based estimating in current estimating practices. This research has shown various important aspects of the BIM-based estimating process and suggestions to improve that process. Although BIM-based estimating is similar to traditional estimating, there are requirements for using BIM to estimate. Mainly, this concerns the creating of a suitable BIM and corresponding recipes to link the BIM directly to construction costs. By addressing these kinds of aspects, this research can support companies to (further) integrate BIM in the field of estimating processes.

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Appendix A: Complexity features and related feature(s) of BIM-based estimating.

As defined in the theoretical context, there are three complexity features. These complexity features have a specific influence on the estimating process or on performing activities within this process. As I show in the table below, I structured my findings by relating complexity features to the five most common errors in quantity takeoff, as defined by Halpin (2006). Next to this, I summarized related features of BIM-based estimating that result from case study three.

As I discussed in section 5.1.3., these complexity features result in uncertainties. The estimator has different ways of accounting for these uncertainties.

Table 2: This table shows the five most common errors experienced during quantity takeoff, according to Halpin (2006).

Errors in estimating	Complexity feature	Related feature(s) of BIM-based estimating
Arithmetic *(Errors in addition, subtraction, multiplication)*	**Technical;** *Difficult calculations* **Resource;** *Number of calculations increases, en therefore probability to make mistakes*	Calculation is done by computer, no errors in the actual calculation. (Formulas however, are made by the estimator)
Transposition *(errors in copying figures, quantities)*	**Organizational;** *Difficulties in communication between different people/companies* **Technical;** *Unclear what is represented by the quantity.*	Information is digital transferred and easier to retrieve. Model should however, be checked before and during the process.
Omission *(Overlooking parts of design)*	**Organizational;** *Difficulties in communication between different people/companies* **Resource;** *Larger scope results in higher probability to overlook parts* **Technical;** *Increases difficulties to check whether or not all is accounted for*	Everything that is modeled in the model is linked to a recipe (control is possible). Things that are not modeled can be accounted for by a recipe (which is linked to an element of the BIM).
Poor reference *(scaling from papers instead of using dimensions indicated)*	**Technical;** *Indicated dimension might not be sufficient. Retrieving right quantities from complex design is more difficult*	Quantity takeoff is done by computer; estimator only requests the right kind of quantities. Current software cannot take into account special conditions (like curvature).
Unrealistic waste or loss factors	**Technical;** *Uncertainties whether or not factors are correct under circumstances.*	n/a, estimator has to determine factors

Appendix B: Working instruction BIM-based estimating (Dutch)

During my research period, I also wrote a concept version of a working instruction. In this instruction, I described the BIM-based estimating process, process steps and the responsibilities of the people involved. I also described various trade-offs that have to be made and what aspects may be important in these tradeoffs. Last, I proposed various ways to standardize or structure BIM-based estimating.

By discussing this instruction, I could evaluate opinions of the people involved in the process.