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- Congratulations to the winners!

Mario Vanhoucke

PROJECTMANAGEMENT

Academic year 2015 - 2016
Prof. Dr. M. Vanhoucke

"De Waalse Krook"

Risk Assessment using the Fuzzy Set Theory

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Preface

In the following paper we will use the Fuzzy Set Theory in order to describe risk assessment in a construction project. We will base us on the construction project “De Waalse Krook” which is located in Ghent. To get a good overview of the project, we visited the site of De Krook where we were guided by the project manager who explained the progress of the project to us. After a short introduction of this project, a general description of the execution and a general description of the risks, we will describe the Fuzzy Set Theory more in detail. We will also adapt this theory to the project of “De Waalse Krook” and conclude whether this approach adds value to the risk assessment of a construction project or not.

1. Background information about the project

1.1 What is the project "De Krook"?

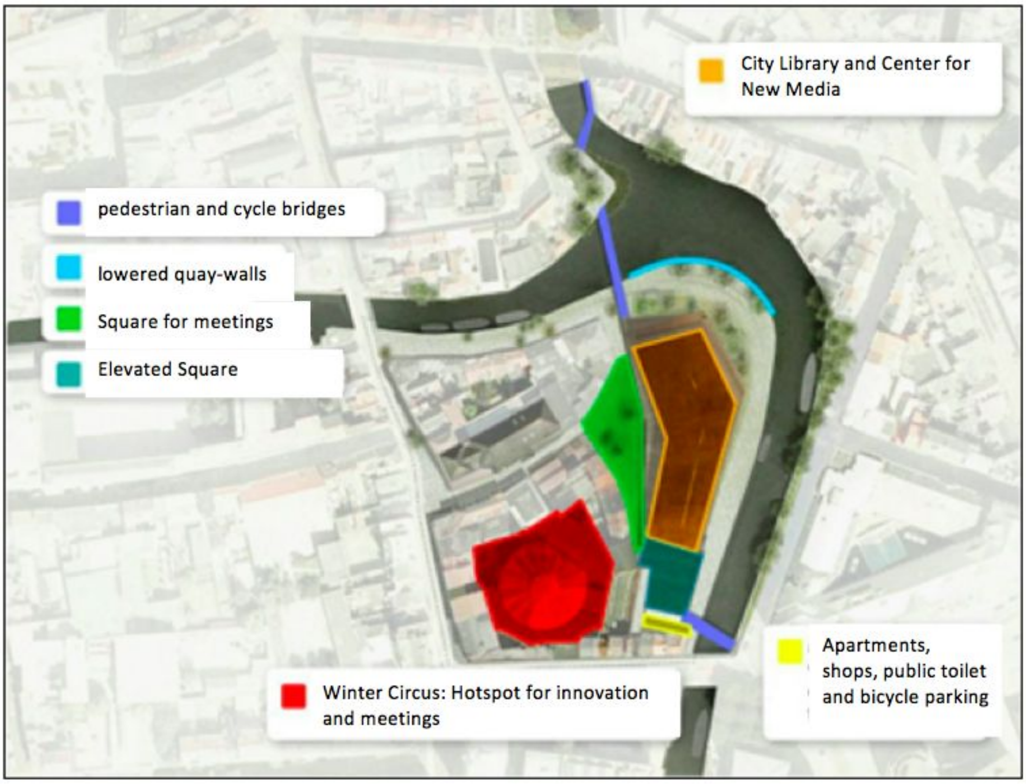
Two years ago, "De Waalse Krook" was still a gigantic building excavation. Today you can already see the outlines of the new city library in a building as big as the size of a football field.

The very ambitious project is transforming about 4000 m² of the city centre of Ghent into a completely new area that will link the more modern part of the city "Het Zuid" with the historical centre. The most important part of the project is the construction of the new city library and the centre for new media. Although the construction of the city library is the main subject of the project, you will be able to do a lot more at "De Krook" than just loaning books.

In fact, the whole neighbourhood around "de Krook" will be reconstructed. Squares, quays, pedestrian and cycle bridges and new connections with the city centre will be build. The city of Ghent believes that the project will make the area "Het Zuid" more attractive and lively again.

The project consists of **three** parts, also shown on the picture below:

- ❖ The **main building** consists of the City Library and the Center for New Media. The building will be a center for knowledge in a digital area. The main building will also provide offices for the University of Gent , the companies iMinds and the relay company REC.
- ❖ The **Public space** will include two new pedestrian and cycle bridges, a raised central square and lowered quay-walls.
- ❖ A **Housing project** with four apartments and commercial buildings.



1.2 Who is responsible for the execution?

There are a lot of different stakeholders in this project. The project is a collaboration between the City Ghent, the entrepreneur Sogent, the Flemish government, the University of Ghent, iMinds and the province of East-Flanders.

The city of Ghent is the master builder of the public space. Sogent is the master builder of the housing project behind the Lammerstraat. The organisations “RCR Arande Pigem Vilalta Arquitectes” and “Coussée en Goris” provided the winning design concept for the new library and the centre for New Media, called “Het Centrum voor Media en Informatie”. They developed the master plan for redesigning the whole area of “De Krook”.

1.3 What is inside?

Gigantic cranes, very busy men in fluorescent vests, scraping noises from grinding discs...That is the current life at “De Krook”. But what can we expect within a year?

1.3.1 Research

There will be done a lot of research in “De Krook” and people will be able to participate in research studies themselves. The University of Ghent will bring several research teams to the offices in “De Krook”. The relay company REC will organise its media workshops at De Krook and will bring its media lab to the Site. There will be a strong collaboration with iMinds, the Flemish Strategic Research-centre for ICT. The collaboration brings together top talents and makes the investment in the necessary infrastructure possible.

1.3.2 Innovation

The project is innovative in terms of services, research and architecture. At De Krook, innovation is converted into entrepreneurship. For example, start-ups are being helped in their launch by the incubation centre iCUBES. In addition, the many meeting places bring people together so that new products and services can find their way to the client. De Krook wants to create close cooperation between different companies resulting in innovative ideas.

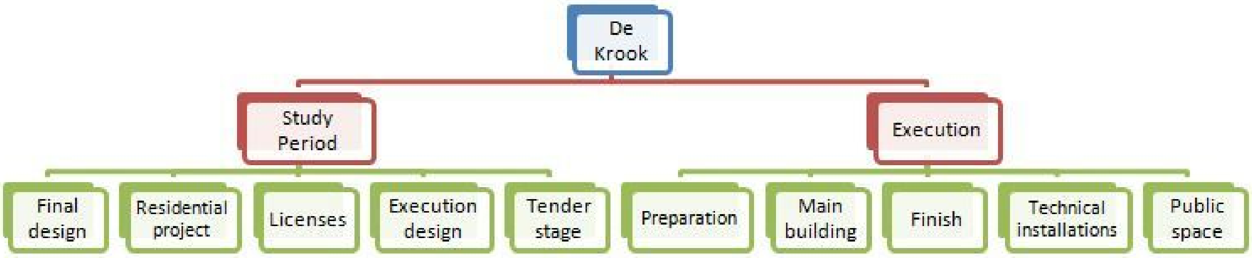
1.3.3 Art and culture

At De Krook, people will be able to admire several exhibits and enjoy multiple events and concerts. Science, art and culture are being exposed to each other.

1.3.4 Meeting points

The time we win due to the new technology, can be used to take time. You can take time on one of the numerous meeting places: the reading café, the “stiltezaal”, the “Miriam Makeba” square, the “Nelson Mandela” promenade, the rooftop restaurant, the “Krook-Café” and the concert hall. At De Krook, knowledge goes hand in hand with reflection.

2. General project description



The general project is characterized by the so-called *Work Breakdown Structure*. It consists of two big periods: the study period and the execution period. The **study period** was planned to begin the 8th of November 2011 and had a duration of 720 days. The study period consists of 5 work items: final design, residential project, licenses, development of execution design and tender stage. Every step of the project was precisely planned and licenses for the main building, public space and housing project were requested. The approvals of those licenses were part of the critical path of the project schedule. Other important activities that were part of the critical path, were activities that concerned controls and approvals in the tender stage. It is a well-known fact that when one of the activities of the critical path is slowed down, the whole project will be late. This was also the case for De Krook. During the study period, they faced some problems with the approvals of the licenses and the whole project was closed down for 2 months. They had calculated those risks in the study period, but they assumed it had a probability of only 30 %. Since the importance of the risk was high, it had some important damages on the execution of the project, which was translated in the 2 months of shut down. The end of the study period was originally planned the 30th of October 2013.

When the designs were drawn and the licenses were approved, the **execution period** could start. It was planned to start on the 29th of August 2012, which means that it started before the start of the tender stage of the study period. The execution period had a planned duration of 916 days and consists of 5 project items: preparatory work, execution of the main building, finishing works, technical installations and public space. We will describe each part in more detail below.

In what follows, we will give a short general description of these five project items where we will describe more in detail the baseline schedule of the building of the public space. The main focus of our paper is to explain the major causes and risks of the serious delays the project team faces. After a description of the general risks, we will analyze the management of the public space more in detail by using the Fuzzy Set Theory .

2.1 Value of the works

In the table below, you can find an assumption of the costs of all the activities of the five main parts of the execution period. These are assumptions of the costs when everything goes according to plan.

Total value of the works	**51 103 848 EUR**
Preparatory Works (groundwork and healing)	1 257 111 EUR
Closed Structure	35 887 901 EUR
Finishing Works	4 280 210 EUR
Technical Installations	10 935 737 EUR
Public Space (two small bridges for pedestrians)	851 162 EUR

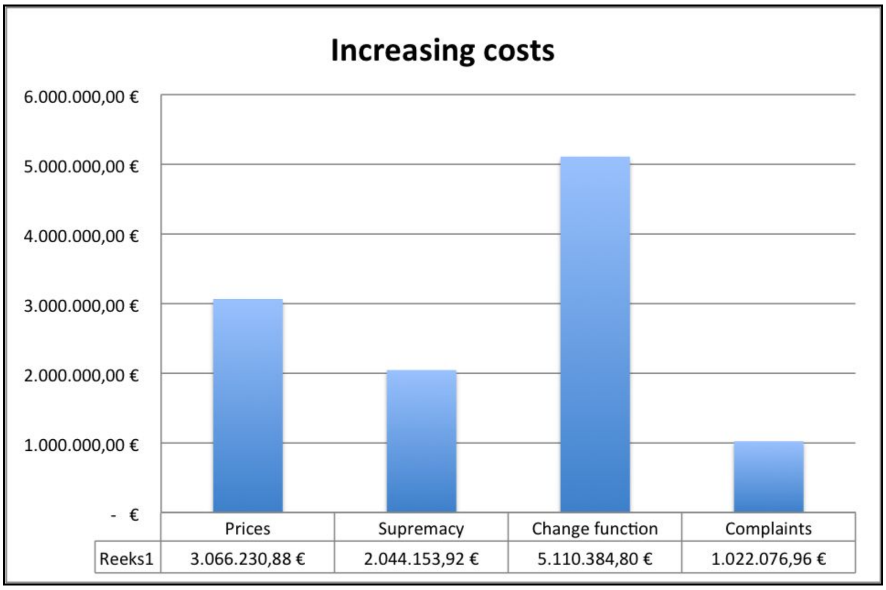
Of course, there are some risks that were calculated in the study period that could strongly increase these costs. We know that risk is different for everyone and in order to define risk, we need the probability that something can go wrong and the impact of it when it occurs.

One of the risks they calculated as being very important with a high probability was the risk of unexpected increases in the price of materials, raw materials and loans. Since there was low economic activity when the project started, these increases in price were considered to happen with a probability of 60 %. It would cause an increase in costs of about 10%.

Another important factor that De Krook considered as a risk were circumstances beyond one's control like natural disasters and terroristic attacks. This would increase the cost by almost 20 %, but they estimated these disasters and attacks had only a probability of 20 %. Maybe it's a good plan to increase this probability change in times like these.

The only risk that would cause an increase in costs of more than 20 % is the risk that the function of the main building would be changed. Even though this would mean that De Krook would lose their subsidies, the risk is not seen as threatening since it has only a 20% of occurrence. (It will increase the cost with about 50%).

Another risk that is likely to happen with a probability of 40% is the complaints of neighbours. Ghent is a university city so during the exams they are likely to get some complaints of noise pollution. This risk would not increase their costs dramatically. It has an impact of less than 5% on the total costs. In this figure we made an estimation of the most important costs that would increase the total project costs by taking the probability and the impact of these risks into account.



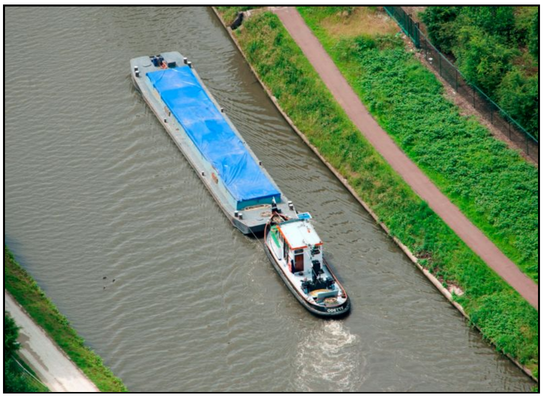
Later on in this paper we will explain the Fuzzy Set Theory which gives a more combined overview of the impact risks might have on the project. We think the point of view of the project manager concerning the impact and probability of the risks was over-optimistic. Based on our study of their baseline schedule and the current situation we may say that their initial cost and schedule was not so realistic.

2.2 The Execution Period

2.2.1 Preparatory work

The preparatory work consists of demolition, archaeological investigation, soil investigation and soil remediation. The works were originally planned to begin the 29/08/2012 and had an original duration of 234 days.

As we will describe in the risk analysis, De Krook calculated that there could be problems with the transportation of materials and scrap because the Schelde was not deep enough. Unfortunately, this risk occurred and there was already a delay in this phase of the project because of the presence of scrap in the Schelde that hampered deepening the Schelde. A significant amount of bikes (Ghent is a student city), refrigerators and even wheelbarrows was brought up by divers.

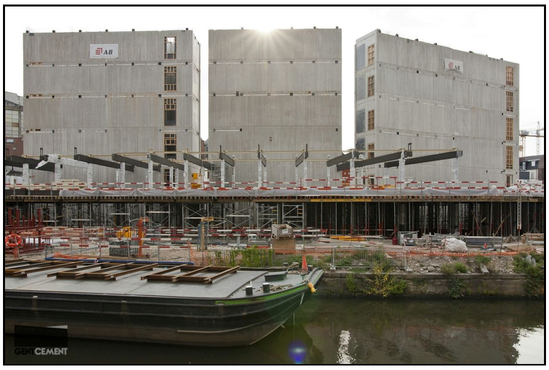


The scrap and soil was transported in small batches and was shifted on to bigger ships near 'De

Ringvaart'. Because of the carrying off with small ships, the duration of this transportation was longer than expected. It was impossible to transport all the soil, so the rest was used for making the concrete in later phases. Even though this type of transportation caused little delays, it was a smart choice to use small ships instead of trucks. The advantage was that it was better for the environment, did not have any impact on traffic and did not cause any noise pollution for the neighbours. This last one was a calculated risk that would increase the cost as mentioned before. De Krook was able to avoid this extra cost and complaints thanks to the transportation via water. The preparatory works were planned to end on 02/09/2013.

2.2.2 Closed Structure

The start of the building of the closed structure was planned on 17/04/2013 and had an original duration of 368 days. At the end of 2013, two gigantic cranes were placed near the excavation and the first part of the concrete foundation was casted. 2014 would become the building year for De Krook.

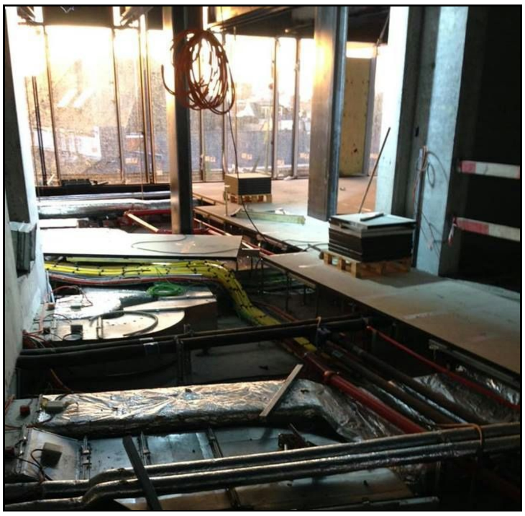


On 12/03/2014, the foundation was ready and it was time to begin with the works at the surface. Four months later, three big concrete cores of six floors high rose up from the docks. It was an exceptional view for those who walked by. The three concrete cores for the spine of the closed structure and contain elevators and stairs.

Each week, the stages of the building kept growing. The complex structure of the building only allowed to finish one stage per month. If everything went according to plan, the team of De Krook estimated to finish the fourth stage by the end of December, which was two months later than planned (25/10/2014). Thereafter they began with the placement of the facade, which needed to assure that the building was windproof by half 2015. On the 14th of July, the team still needed to make two stages windproof, as you can see on the picture below. We can state that they did not achieve their planned goal. The delay was mainly due to bad weather conditions and limited access to position the cranes near the building, which will be explained later..

2.2.3 Technical Installations

The technical installations are integrated in the architecture and structure and co-decided the architecture of the building. The empty concrete cores will be used as ventilation systems and will regulate the temperature. High windows will let a lot of daylight enter the building.



The temperature regulating systems are integrated in the floors and ceilings of the building. Originally, the start was planned for 20/01/2014 and these works would take one year. However, these works are only finished on the highest floor. On the other floors, the crew of De Krook is facing some problems since some parts of these structures are installed too high and the floors cannot be placed before these structures are lowered. The firm who is responsible for the installation of these structures is not available for the moment, so that is the reason for the delay in the technical installations part. On the picture, you can see one of the trouble zones where the floor is not placed because of these high structures. This was an unexpected event, since the risk was not calculated in the study period.

2.2.4 Finishing Works

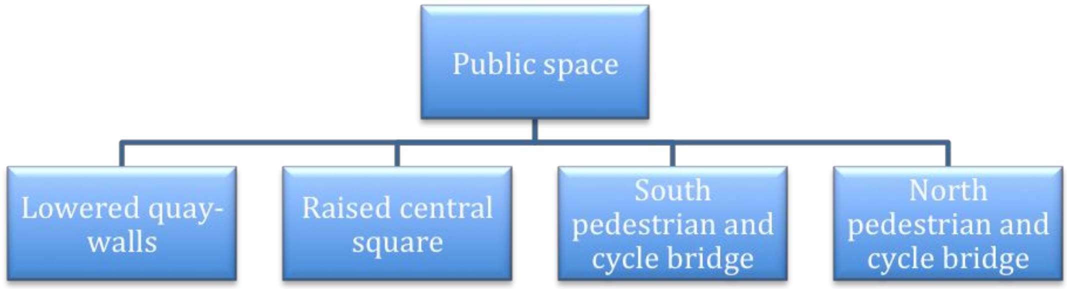
This part of the project was planned to start on 18/04/2014 and had a planned duration of 319 days. Due to some delays, the schedule for the finishing works was adapted and the works started half 2015. For the moment, the floor and ceiling are only placed on the fourth floor. The walls of glass still need to be placed everywhere. The risk of bad weather conditions cannot occur in this part of the project, since the finishing works take only place inside the building. In consequence, the delay is not due to the weather, but it is caused by the technical installations being installed too high. When this is done correctly, the team of De Krook can easily continue with the finishing works. The original deadline of 02/03/2015 is not reached at all.

2.2.5 Public Space

The construction of the public space has three goals: rebuilding the site De Krook, adjust the crossroad Kuiperskaai-Lammerstraat and improve the cycle connection between De Krook and Brabantdam. This will be achieved by the construction of a square, two bridges and renewed quay walls. The public space will consist of two zones, an acreage and a pedestrian and cyclist zone. The purpose is to make this last zone a traffic free green place. Cars can be parked in the nearby underground car park of “Het Zuid”. The public space will be transformed in a qualitative place where people can quickly pass by or stay for a while and a place where mechanical traffic has disappeared. There will be berths for pleasure and taxi boats, an underground bicycle parking and terraces on the square. The presence of cultural functions and the traffic free character will encourage a lot of people to move between the historical centre and the transportation interchange along this way.

In order to analyze the planning of the public space, we will compare the original baseline schedule with a more recent adjusted baseline schedule (see Exhibit 1 and 2). There were and are some substantial delays and we will analyze the causes and consequences. This 'original' baseline schedule is not really the original schedule, but it is the one we received from the project manager of de Krook. The very original due date for the public space was 02/03/15, but this clearly was a big underestimation since they are still working on it.

If we look at the Work Breakdown Structure, the public space can be broken down into four work packages:



Every work package consists of activities regarding to structuring work and finishing work. The different activities are described in the baseline schedule. For every activity, you see the duration, the start date and the finishing date. You also see the precedence relations (mostly finish-start) with the time-lags.

According to the "original" baseline schedule, the planning of the public space was the following:

- start date 10/10/13
- finishing date 02/03/16
- duration of 1452 days

We see that on this original schedule, one activity is already been added: 'extra execution time for public space because of extra order quay renovation part D'. Thus, because of problems in another work item ('part D'), the public space will take 41 days longer. In the next paragraph we will explain this risk of access blocking more in detail.

If we look at the adjusted baseline schedule, we see that the start and finishing date have been changed. The part of the public space started on 09/08/14 which sums up to a delay of 10 months. The finish is now planned on 29/04/16. What are the differences between the original and adjusted schedule?

In work package 1, one activity has been added, named 'extra execution time because of equal end with working at the province house" with a duration of 41 days. The project manager told us the 'Kuiperskaai' (their main way to transport goods and machines) would be unreachable for more than a month due to workings at the Province house. Consequently, the end of the public space is planned on 29/04/16 and not on 02/03/16.

The construction of the raised central square did not start on 10/10/13, but on 09/08/14. This delay is caused by some unexpected events which we will explain in our risk analysis. Moreover, extra activities with extra durations regarding to roof insulation and flooring are added. The project manager told us they were confronted with a bad environmental report, so they needed additional insulation for the apartments. Therefore, the end is not planned on 19/11/15, but on 12/04/16 which is a delay of 146 days.

The construction of the south bridge started on time, but it will not be finished on time. This is caused by a delay of the activity 'pour concrete at bridge deck'. Normally, this activity should have been started on 08/09/15, but it will only start on 03/12/15. In consequence, the subsequent activities also experience delays. The construction of the south bridge will normally be finished on 05/02/16 which is a delay of more than 3 months.

We see the same story with the construction of the north bridge, except here, there is only one activity with a delay. Because of problems with the horizontal aluminium fins, this activity will start 20 days later, resulting in a delay of the finishing of the north bridge of 20 days.

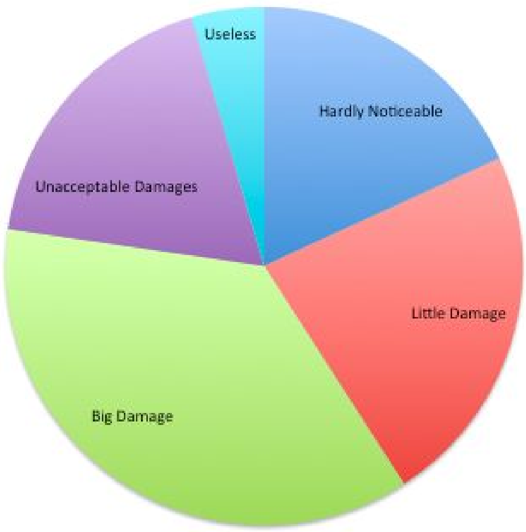
The final end of the whole project and the putting into use was planned on 15/06/2015. It is very clear that the project did not finish within the planned time. Now we will analyze the risks that led to the project delay and, more specifically, risks that led to the delay of the public space.

3. Risk analysis

3.1 General description of the Risks

3.1.1 Common risks with a high impact on the general execution (duration) of the project

Construction projects are initiated in complex and dynamic environments resulting in circumstances of high uncertainty and risk. That's why risk analysis is very important in this context. According to the information we got from the Krook, we need to consider that the execution and planning of the project are accompanied by some important risks. The risks are divided into five categories. The lowest category represents the risks that are hardly noticeable. A next category describes the risks that damage narrow pieces of the project. The third category of risks, which is the most frequent one, stands for the risks that damage important pieces of the project. A fourth category represents risks that cause unacceptable damages for the main builder. An occurrence of the last category of risks makes the project useless and will



end the project immediately. The division of the risks for the Krook among these categories is shown on the pie chart. As you can see, most risks of de Krook are from category three or lower. Another specification of risks is that they are all indicated by a probability chance and an importance factor. Only when this importance factor is above one, the risks are considered to be important to follow up and must be avoided.

The most important risks are considered during the execution of the project. Within the general project execution, there are two risks very likely to happen. The most threatening one, with a probability of 70% and an importance factor of 1.2, is the need for an extend in the utility lines. This would cause a cost a lot higher than originally estimated. There was also a 50 % chance that the attainability of the fire corps would be limited during the progress of the project.

Other risks with a lower probability but a high importance factor are the risk of 'problems with the quay-walls' and 'obligation of Ghent City to transport via water'. Even though these two risks had a probability change of only 40 %, they did occur and damaged important pieces of the project. The problems with the quay-walls slowed down important parts in the program and is considered as one of the reasons the project is late. Because of the condition of this wall, the cranes could not be placed and the project was slowed down about 10 %. The transportation problem costed the company a lot of money. The main problems were that the Schelde was not deep enough to transport all the junk, it was hard to cross and anchor, there was a limited height under the bridges and problems on the river could obstruct the whole logistics. It was a very important factor that slowed down the project with another 10 %. De Krook expects, with a probability of 80 %, that the start of the execution of the Wintercircus will also slow down the completion of De Krook. They believe it will cause obstacles for the opening of De Krook. Another problem concerning the transportation is the limited access of their main road 'De Kuiperskaai' due to working at the Province House which is situated in the neighbourhood. This risk belongs to the third category and will damage important pieces of the project with a longer duration as a consequence.

3.1.2 Public Space

The bridges are considered as a difficult part of the project. The risks are only from category two, but have a high probability chance and importance factor. They expected to face the technical complications with the structures in the floor and additional costs for finding solutions for placing the bridges.

3.2 Some unexpected events

The execution of the new library and the "research centre for media and information, art and culture" was stopped by the "Raad voor Vergunningsbetwistingen (RvVB)" because project developer V.O.P. had made a complaint concerning expropriation. Consequently, the building license had been destroyed and the project was shut down from the 17th of November 2014 until January 2015 which was more than two months. In December, the RvVB announced there was made a new building license, and the works could be restarted 36 days after this announcement. The project manager of De Krook knows the building licence is an essential part for the continuation of the project, that's why he considered this risk as one of the highest category with a huge impact on the duration and costs as a consequence. Unfortunately, he underestimated the probability this was likely to happen during the project. He only considered the risk of a dispute from third parties at the beginning of the project.

Today, the public space around the major building already has a delay of approximately one month and they have to pay attention to some unexpected events that could cause an additional delay. There are different crucial factors that have led to this hold-up. One factor is related to the needed space. They had to wait several weeks for specific materials needed for the execution, as shown on the picture on the right. According to the manager, this was not a serious problem for the reason that a lot of work at the outside of the building must be completed first. Many materials, needed to complete the exterior of the main building, needed to be stocked at the elevated area around the building. Therefore, it was impossible to start the works of the public domain. At the moment, they can reach the different floors with cranes placed at the quay-wall, but in a few months, the quay wall will be no longer available because of the works that will start there. Consequently, they also need the space around the building to finish these works outside the building.

Another aspect that has to be taken into consideration are the weather conditions. They cannot be predicted months in advance, because they are very variable from day to day. When they have to mould the concrete, they have to be sure it won't frost or rain the following days. Otherwise, some serious problems can arise. While the concrete hardens, they have to avoid cracks due to rainy weather and cold. The concrete is a sensitive part for the duration of the whole project. Once the concrete is moulded, they have to wait a month because it has to dry out. After a month, an inspection of the concrete can take place. If it looks good, they can start to rub down 3 millimetres and blast it.

The apartments which are also part of the public domain had also some retardations. There was a problem with the insulating values. Therefore, they needed to wait for a permission to continue the works.

4. Fuzzy Approach

4.1 What is the fuzzy approach?

Poor performance is often the result of risks occurring in a construction project and the lack of a formalized approach leads to increasing costs and time delays. This is also the case for De Krook. We know De Krook uses some risk matrices based on previous experience from engineers in construction projects. When a previous construction project is similar to the new one, these risks might provide a good insight on the impact (severity) and the probability they might occur.

Unfortunately, these matrices do not provide an insight in the overall impact these risks might have on the project duration and costs. With the need for improved performance in the construction project and increasing contractual obligations, the requirement of an effective risk management approach has never been more necessary. In this section we will focus on the overall impact of risks on the public domain.

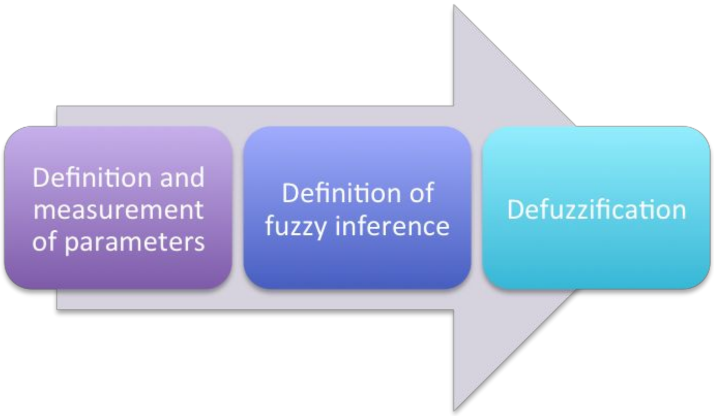
Since risk assessment is such a complex subject full of vagueness and uncertainty, project managers often use vague terms because they find it easier to describe risks in qualitative linguistic terms. However, in these days construction projects are becoming increasingly complex and dynamic so we provide a new approach: a risk assessment methodology based on the Fuzzy Sets Theory, which is an effective tool to deal with subjective judgment. It is also based on the Analytic Hierarchy Process (AHP), which is used to structure a large number of risks.

Fuzzy Set Theory enables qualitative risk assessment descriptions to be modeled mathematically. Cause and effect diagrams represent the relationships between risk factors, risks, and their consequences, which enables identification of risk sources and their consequences on the project performance measures. Risk project management is beneficial if it is implemented in a systematic manner from planning stage through the project completion. A methodology for representing the risk exposures in terms of time, cost, quality, and safety changes is presented in the following paragraphs.

Effective risk management involves a four-phase process:

Risk identification: Which risks may affect the project? Determining their characteristics.
Risk assessment: Prioritizing risks for further analysis by assessing and combining their probability of occurrence and impact.
Risk response: Developing options and actions to enhance opportunities and to reduce threats to the project objectives.
Risk monitoring and reviewing: Implementing a risk response plan, tracking identified risks, monitoring residual risks, identifying new risks and evaluating the risk process effectiveness throughout the project.

The fuzzy risk assessment method consists of three steps:



1° **Definition and measurement of parameters:** The fundamental parameters are risk probability and risk severity. It is very difficult to measure these parameters because of the uncertainty of the risks. The measurement of each parameter is made in vague data or linguistic terms and converted into its corresponding fuzzy number.

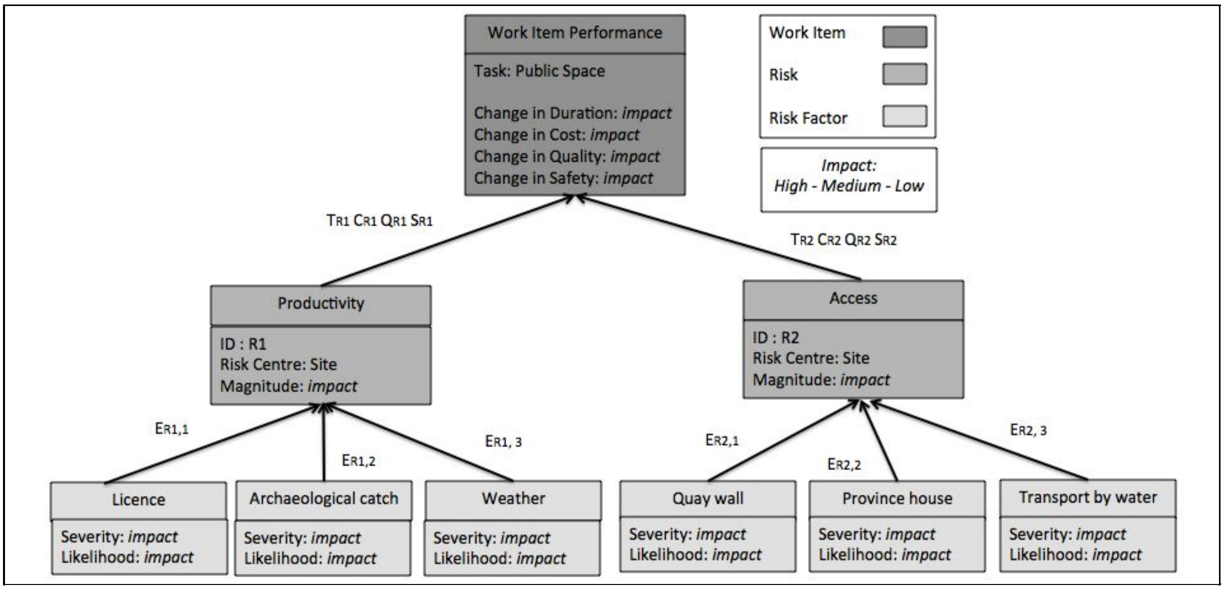
2° **Definition of fuzzy inference:** The relations between input parameters and output parameters can be defined in form of "if-then" rules or in form of mathematical function defined by an appropriated fuzzy arithmetic operator.

3° **Defuzzification:** As the result of a fuzzy inference phase is a fuzzy number, this step is used to convert the fuzzy result into an exact numerical value that can adequately represent it.

We will explain the procedure we will follow to define the risks of De Krook in the following paragraphs.

Experts with high experience in rehabilitation projects of buildings are selected to form the risk assessment group. For De krook, some engineers of the firm A-Res are assigned the task of defining the schedule of the project and defining and incorporating the major risk factors. They identify the risk sources and construct hierarchical structure of risks, or the so called "Hierarchical Risk Breakdown Structure (HRBS)". This provides the basis for a stratified classification of risks. Risks are defined by the part of the project they affect, and are themselves affected by risk factors that affect the project indirectly. The key attributes of risk factors are likelihood, severity, and timing.

In figure 1 below, the HRBS is applied on the case of De Krook for a part of the public space. The top node represents the local risk associated with a work item, which is here the execution of the public space itself. The second level represents risk sources (Productivity and Access). The third level represents the risk factors that influence the risks. The nodes linked by directed arcs represent dependencies or cause and effect relationships. Absence of an arc between two nodes represents independence. The likelihood is defined as L, the severity as V, and the effect of a risk factor as E. The fuzzy set approach assumes that risk factors affect the severity of risks, which causes changes in the performance measures of a project, namely time, cost, safety and quality. These measures can act as symptoms to be observed when monitoring a project, which means that the risks with a high impact on the performance will be subject of the risk response phase. The figure provides a cause (risk factors) and effect (symptoms) diagram. Analyzing the causality between risk factors and risks and the causality between risks and performance measures determines the changes induced in the work item performance.



We will complete figure 1 by calculating the severity, likelihood, magnitude and change in duration, cost, quality and safety. In order to do this, we used the mathematical theory behind the fuzzy set approach which is added in appendix 6.1. In the next paragraph, we will adapt this mathematical approach to the project De Krook.

4.2 Fuzzy Approach applied on De Krook

We will consider the risks associated with the work item public space. The first step includes identifying the risk sources. After studying the risks of the whole work item of the public space we put some risks together that might have a large correlation and we distinguished two groups of risk sources.

One of the biggest risk sources according to us affecting the public space is the continuity of the **productivity.** We identify three risk factors:

- The rejection of the licence to execute a part of the public space. We can give an example of a risk factor that was very likely to occur: defining the position of the end of the bridges was not as easy as it seems, it may cause a problem to get an approval to execute the works on the street within the predefined schedule.
- Archaeological catches: Since the city has a large cultural history they had found a lot of discoveries from ovens which were used for the tanner's trade to old buildings from the industrial period. These findings are a huge risk to affect the productivity because they couldn't expect what to find in the lower layers of the ground, so the ground conditions can affect the productivity.
- Weather: As we mentioned above weather can have a great impact on the duration and costs of the project.

The other one is the risk due to workings in the neighbourhood which will affect the **access.** We identify again three risk factors:

- Workings at the quay wall will make it impossible to complete the exterior of the building and this is the main cause why the public space has such a delay as we mentioned before. This can also cause additional costs if they decide to make a foundation for the cranes. We need to make a trade-off between these costs or additional delays, because we want to optimize the time and cost at the same time.
- As we already mentioned, workings at the Province House will make it difficult to access the main road to the site.
- There is also the obligation of the city of Ghent to transport only by the water.

The Fuzzy Associative Memories (FAMs) that relate the risk factors likelihood and severity to the magnitude of the risk are shown in the table below. This shows the rule-set defining the likelihood and severity of a given risk with its magnitude value. A numerical significance factor can be used to add even more mathematical value to the model. The factor is used to calculate the significant influence of the risk in the project by multiplying the scales of the likelihood and severity which results in the magnitude. More information on this calculation is given in the appendix.

The main approach of this method is not to identify a list of risks but to ascertain the key risks that can significantly influence the delivery of the project. Using this significance factor we can rank the risks according to their significance factor and focus only the top ten ranked ones that are chosen as key risks to focus on. Since we already have a notion of the most important risks because of the risk matrices we don't need to identify them, but it can be useful for other projects.

Risk severity	**Risk magnitude**				
High (1.0)[1]	Medium	Medium	Medium High	High	High
Medium High (*)[1]	Low Medium	Medium	Medium	Medium High	High
Medium (0.5)[1]	Low Medium	Low Medium	Medium	Medium	Medium High
Low Medium (*)[1]	Low	Low Medium	Low Medium	Medium	Medium
Low (0.1)[1]	Low	Low	Low Medium	Low Medium	Medium
	Low (0.1)[1]	Low Medium (*)[1]	Medium (0.5)[1]	Medium High (*)[1]	High (1.0)[1]
	Risk likelihood				

Table 1

[1] More information on the risk significance index scales is provided in appendix 6.2. In this paper we opted for a more general model, as explained in the appendix.

The second step involves the assessment of the likelihood and severity of the individual risk factors of the risks productivity and access (the severity and likelihood are mentioned on the risk matrices from The Krook). Using these assessments, we can calculate the magnitude of each risk factor based on table 1. The relationship between the occurrence L, the severity V, and the effect of a risk factor E is described as “IF L AND V THEN E “.

Risk	Severity (=V)	Likelihood (=L)	Magnitude (=E)
Productivity			
Licence	High	High	High
Archaeological catches	Low	Low	Low
Weather	High	Medium	Medium High
Access			
Quay wall	High	Medium High	High
Province house	High	High	High
Transport by water	High	Medium High	High

Table 2

The value of the risk factor with the greatest effect (E= jE_{max}) determines the total effect on the risk. Assuming that j is equal to one, we can calculate that for both productivity and access the risk magnitude is high.

The final step involves computing the changes induced in the performance measures of the work item by the individual risks. Given a risk with a severity effect E, the changes in time T, cost C, quality Q, and safety S induced on a task can be represented by the following rules:

IF E THEN T
IF E THEN C
IF E THEN Q
IF E THEN S

In table 3 below, the fuzzy associative memories relating the risk magnitude value with the changes it induces in the work item or tasks performance measures are shown. Therefore, we determine the changes in the performance measures for the three scenarios based on the risico matrices of The Krook, both for the productivity and access risk:

	Risk magnitude	Change in duration	Change in cost	Change in quality	Change in safety
Productivity	High	High	High	High	Low
	Medium	Medium	Medium	Medium	Very low
	Low	Low	Low	Low	Very low
Access	High	High	High	Medium	Medium
	Medium	Medium	Medium	Low	Low
	Low	Low	Low	Low	Low

Table 3

Since we calculated that the risk magnitude of both risks is high, we derive from table 3 the following impacts:

	Risk magnitude (=E)	Change in duration (=T)	Change in cost (=C)	Change in quality (=Q)	Change in safety (=S)
Productivity	High	High	High	High	Low
Access	High	High	High	Medium	Medium

Table 4

Based on the previous rule that the value of the risk with the greatest effect ($E = jE_{max}$) determines the total effect on the risk we calculate:

$T = j\ T_{MAX}$ = high
$C = j\ C_{MAX}$ = high
$Q = j\ Q_{MAX}$ = high
$S = j\ S_{MAX}$ = medium

These equations represent the total changes to the performance measures time T, cost C, quality Q, and safety S of a given task. The linguistic variables which are represented by the given fuzzy sets can be determined by defuzzification. We can now improve the HRBS structure (see Figure 1) with the calculated impacts. The result is given in figure 2.

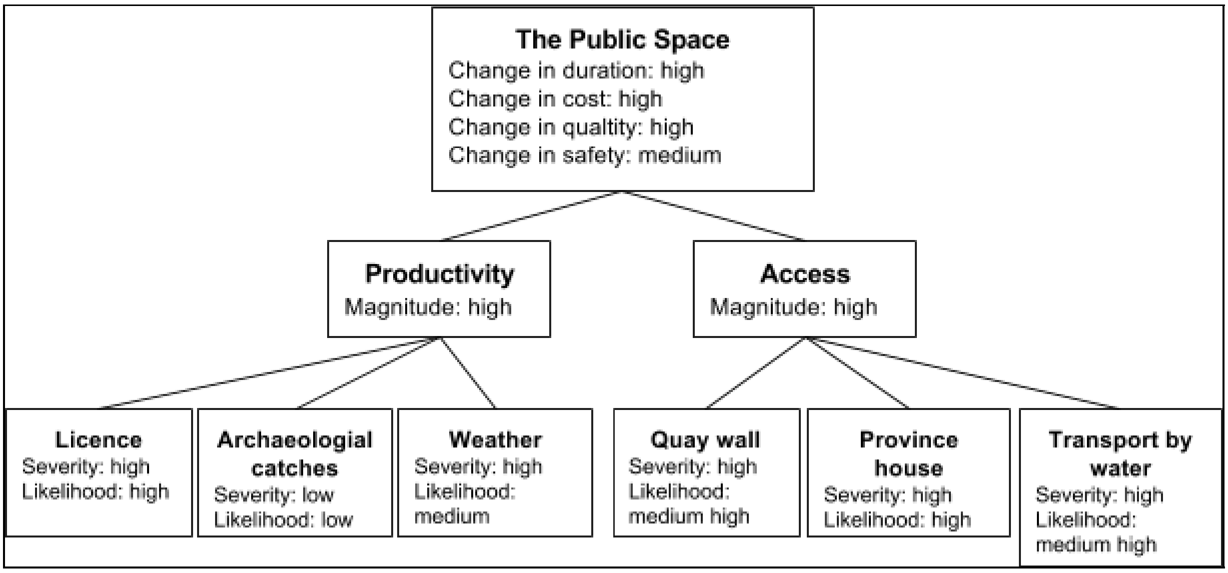


Figure 2

4.3 Prototype Software System

To test and implement the Fuzzy Set Theory, a prototype software system has been developed. The system consists of a single user-friendly interface which controls all aspects of the risk management process and controls access to the data sources automatically, integrates with a database management system, project planning software, and a word processor, allowing the system to seamlessly access all risk and project information as required. Therefore, there is no knowledge required of the manner in which the data is stored and manipulated. The system has been developed using Microsoft Visual Basic, and can be used by Microsoft Windows 95/98 or NT4. For the moment, the prototype is only used as a basis for discussion with practitioners about the practical requirements of the fuzzy approach for further development to satisfy the needs of the construction industry. The aim of the software is to facilitate practical and effective risk handling in order to develop a greater understanding of project risks, resulting in improved performance.

5. Conclusion

A formalised risk management process is still rare within many construction organisations and risk management must become an accepted part of the construction process, much like planning and financial analysis are currently. The Fuzzy Set Theory provides an easy method to rank the risks for a construction project. Using this method results in a nice overview of the overall impact of risk for the project. It is a good method to identify relationships between risk sources and their consequences on project performance measures. According to us, the fuzzy approach gives a better overview of the risks than the use of vague risk matrices that are frequently used in construction projects.

As a general conclusion we can definitely state that the management of a construction project is a very complex task. To complete the project successfully, it is important that the leader of the project is an intellectual, emotionally competent, engaging and goal-orientated person. He needs to be critical and must be able to develop a new insight schedule when business is not going according to plan anymore. He must have a high influence and motivation so he can pass that on to his employees which needs to result in a strong team to make the project a success. Teamwork is not only a very important aspect in a construction project. It is important in every project, because teamwork makes the dream work.

6. Appendix

6.1. Mathematical approach to risk assessment

The relationship between the occurrence L, the severity V, and the effect of a risk factor E is described as "IF L AND V THEN E ". Using the Fuzzy Associative Memories (FAMs) we can represent many such relationships with varying values of L, V, and E. FAMs uses two matrices M_{LE} and M_{VE}.

Given a risk factor with likelihood L' and severity V', the effect or induced fuzzy set E can be found through composition:

$L' M_{LE} = E_{L'}$
$V' M_{VE} = E_{V'}$

The fuzzy logic intersection operator is used to join the two induced fuzzy sets:

$E' = E_{L'} E_{V'}$

This represents the effect E' for an individual FAM. If m rules exist then the total effect E can be found by :

$E = E'_1 \cup E'_2 \cup \dots E'_m$

This value E is the effect for a given risk factor with a predefined likelihood and severity value. So the conventional fuzzy technique calculates the total effect E on the risk R, which is influenced by n risk factors. However, this technique produces results which are not realistic for risk analysis. Instead, the value of the risk factor with the greatest effect, Emax, is used. The effects of the remaining risk factors may be used to modify this by a further amount j such that,

$E = j E_{MAX}$

Next, we consider the changes the risks induce on project performance. Given a risk with a severity effect E, the changes in time T, cost C, quality Q, and safety S induced on a task can be represented by the following rules:

IF E THEN T
IF E THEN C
IF E THEN Q
IF E THEN S

We can also construct FAM matrices, M_{ET}, M_{EC}, M_{EQ}, M_{ES} for each rule. Given a risk with effect E', the changes induced in T, C, Q, and S are T', C', Q' and S' and are determined by composition such that

$E' M_{ET} = T'$
$E' M_{EC} = C'$

$E' M_{EQ} = Q'$
$E' M_{ES} = S'$

If there are n FAMs for each risk effect then T, C, Q, S can be determined by

$T = T'_1 \cup T'_2 \cup \ldots T'_n$
$C = C'_1 \cup C'_2 \cup \ldots C'_n$
$Q = Q'_1 \cup Q'_2 \cup \ldots Q'_n$
$S = S'_1 \cup S'_2 \cup \ldots S'_n$

Once again, this technique has produced average results, so the values of T, C, Q, and S from the risks with the greatest impacts are used. The remaining values are then used to modify this by a further amount j for each performance measure affected such that

$T = j\, T_{MAX}$
$C = j\, C_{MAX}$
$Q = j\, Q_{MAX}$
$S = j\, S_{MAX}$

These equations represent the total changes to the performance measures time T, cost C, quality Q, and safety S of a given task. The linguistic variables which are represented by the given fuzzy sets can be determined by defuzzification.

6.2 Calculation of the significance index scale

The average score for each risk considering its significance on a project objective can be calculated through the multiplication of the likelihood L and the severity S. This average score is called the **risk significance index score** and it is used to rank all risks on a particular project objective.

Shen et al. (2001) and Wang and Liu (2004) provide three scales for L (highly likely, likely and less likely) and S (high level of impact, medium level of impact and low level of impact). These scales will be converted into numerical scales using a value of 1 for “high”, a value of 0.5 for “medium”, and a value of 0.1 for “low”. The matrix presented in the table below shows the calculation of the risk significance index.

	Severity (S)		
Likelihood (L)	High impact level (1.0)	Medium impact level (0.5)	Low impact level (0.1)
Highly likely (1.0)	1.0	0.5	0.1
Likely (0.5)	0.5	0.25	0.05
Less Likely (0.1)	0.1	0.05	0.01

As you can notice, the scales “Low Medium” and “Medium High” are not provided in this approach. Since the risks of De Krook uses these last two scales, we can’t apply the approach to the project. We could estimate these values and use a value of 0,25 for “Low Medium” and a value of 0,75 for “Medium High”. However, the significance of these estimations is not proved. That’s why we used a more general approach to apply the fuzzy method on the Krook. Trying to expand the scales and find appropriate values for those scales could be a topic for some future research about this topic.

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8. Exhibits

Exhibit 1: Original baseline schedule of the public space

Exhibit 2: Adjusted baseline schedule of the public space