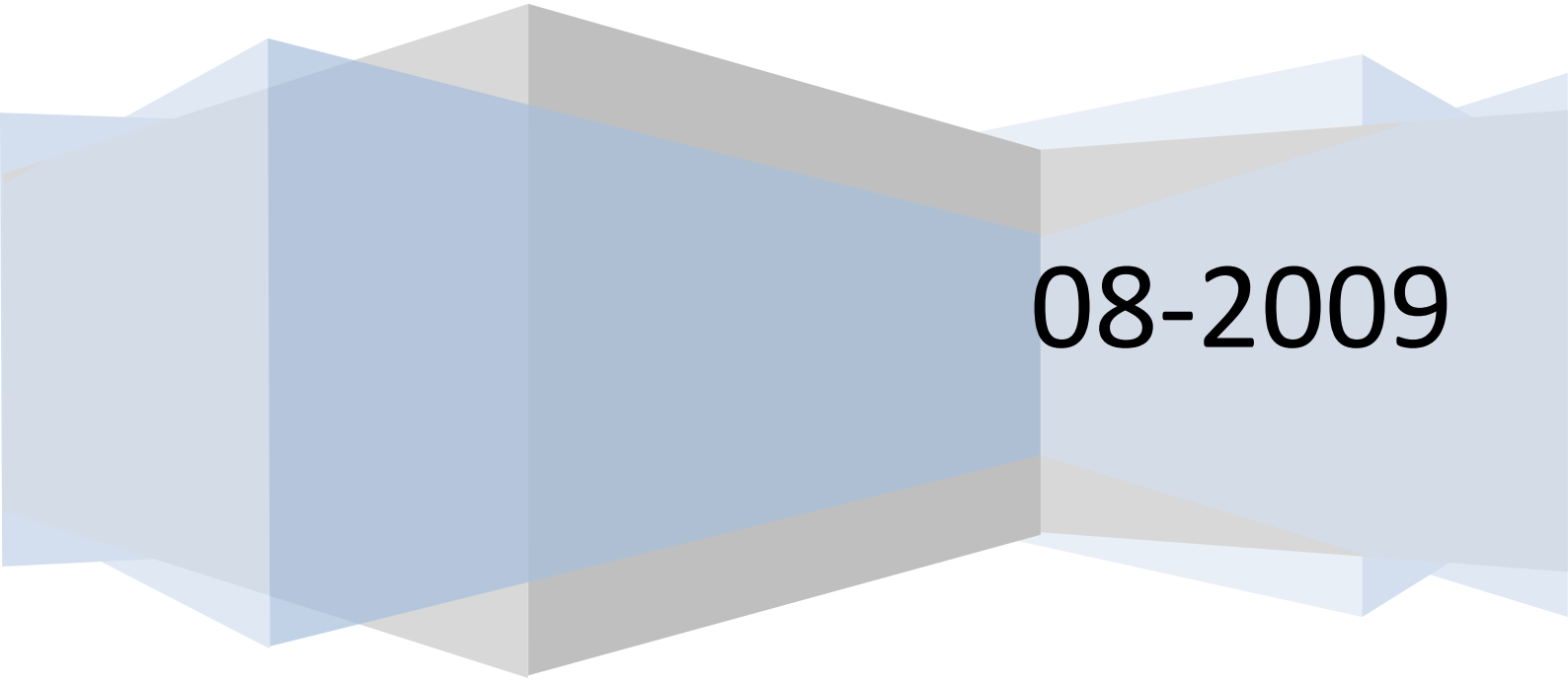
Universiteit Twente – Bachelor Eindopdracht

Risicoweergave in 4D

Onderzoek naar de mogelijkheid om risico's weer te geven in een 4D model bij het deelproject de Fietsenstalling Stationsplein , in het kader van de Bachelor Eindopdracht.

Niels Vossebeld – s0155802



08-2009

Risicoweergave in 4D

Onderzoek naar de mogelijkheid om risico's weer te geven in een 4D model bij het deelproject de Fietsenstalling Stationsplein en het modelgebruik bij Gemeentewerken Rotterdam, in het kader van de Bachelor Eindopdracht.

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Auteur: Niels Vossebeld

n.vossebeld@student.utwente.nl

Instelling: Universiteit Twente, Enschede

Organisatie: Ingenieursbureau Gemeentewerken Rotterdam

Begeleiders: ir. Timo Hartmann (Universiteit Twente, begeleidend docent)

ir. Jaap Bosscha (Ingenieursbureau Gemeentewerken Rotterdam)

Gemeente Rotterdam
Gemeentewerken

University of Twente
Enschede - The Netherlands

Voorwoord

Voor u ligt een bundeling van de eindproducten van mijn Bachelor Eindopdracht. De Bachelor Eindopdracht is een externe onderzoeksopdracht en is onderdeel van de universitaire Bachelor Civiele Techniek aan de Universiteit Twente, te Enschede. Ik heb in het kader van de Bachelor Eindopdracht een verkennend onderzoek gedaan bij het project Rotterdam Centraal. Daarbij is gekeken naar het modelgebruik en de mogelijkheid om risico's in 4D weer te geven, bij het Ingenieursbureau van Gemeentewerken Rotterdam, op de productgroep Bouwen.

Na drie jaar boekenwijsheid vond ik het erg leuk dat ik de mogelijkheid kreeg in de praktijk een onderzoek uit te voeren. Dat ik daarbij in de keuken mee kon kijken bij een groot project als Rotterdam Centraal is natuurlijk super. Mijn interesse heeft tijdens mijn studie altijd gelegen bij de "bouw"-stroming binnen de Civiele Techniek, in het bijzonder bij infrastructurele projecten. Bij het derdejaarsvak ontwerpbenaderingen zag ik voor het eerst een 4D model dat het bouwproces demonstreerde. Toen wist ik al snel dat ik mijn Bachelor Eindopdracht in die richting wilde gaan uitvoeren, "iets met 4D graag". Het gebruik van 4D is een erg nieuwe ontwikkeling, zeker het weergeven van risico's in een dergelijk model. Dit is zover ik weet nog nooit onderzocht. Ik heb erg veel geleerd tijdens het verkennende onderzoek. Niet alleen over de theorie maar ook over de beroepspraktijk en mezelf. De vaardigheden en kennis die ik op heb gedaan zijn volgens mij dan ook van onschatbare waarde voor de rest van mijn studie.

In dit voorwoord wil ik mijn begeleiders Timo Hartmann en Jaap Bosscha bedanken voor de hulp, de aanwijzingen en de kans om bij I-GWR dit onderzoek uit te voeren. Het onderzoek was niet mogelijk geweest zonder de medewerkers bij I-GWR die tijd vrij hebben gemaakt voor interviews en/of demonstraties van mijn werk. Daarnaast wil ik in het bijzonder de modelleurs Peter Doorduin en Raymond Michels bedanken voor de eerste uitleg van de software en het modelleren van de noodzakelijke geometrische 3D input. Tot slot wil ik mijn ouders bedanken voor de steun die ze me altijd geven bij alles wat ik doe, in het bijzonder bij mijn studie.

Niels Vossebeld

Inhoudsopgave

Inleiding

Op grote, complexe, bouwprojecten is het moeilijk om effectief in vergaderingen met betrokkenen over de risico's in het bouwproces te praten. Het is namelijk moeilijk om het bouwproces in te beelden. Een 4D model is één manier om het bouwproces toe te lichten en visueel weer te geven. 4D modellen combineren 3D ontwerptekeningen met planningsinformatie in de computer. Daarmee kan een 4D model alle stadia van het bouwproces in tijd en ruimte weergeven. Dit rapport doet verslag van het onderzoek naar de mogelijkheden om risico's weer te geven in een dergelijk 4D model. Daarbij is tijdens het onderzoek ook gekeken naar het 4D modelgebruik bij Gemeentewerken Rotterdam.

Kern van dit verslag is een Engelstalig onderzoeksartikel. Titel van het artikel: '*A case study on using 4D modeling for risk visualization*'. Dit artikel is geschreven voor de conferentie '*Changing Roles 09',* een conferentie over de veranderende rollen in de bouwwereld. Tijdens de Bachelor Eindopdracht is echter niet alleen dit artikel geschreven, daarom zijn in de bijlage ook twee (concept) eindproducten toegevoegd die zijn geschreven voor Gemeentewerken Rotterdam. Ten eerste een handleiding voor de modelleur waarin wordt toegelicht hoe een 4D model dient te worden gemodelleerd. Deze handleiding kan als een conceptTen tweede een adviesrapport voor projectleiders bij Gemeentewerken Rotterdam. Hier wordt ook verder ingegaan op het 4D modelgebruik bij Gemeentewerken Rotterdam. Daarmee geeft dit verslag een overzicht van de door de auteur uitgevoerde werkzaamheden.

A case study on using 4D modeling for risk visualization

Niels Vossebeld, Bachelor student
Civil Engineering, University of Twente.
Netherlands

Dr. Timo Hartmann, Assistant professor
Department of Construction Management and Engineering, University of Twente.
Netherlands

Abstract

On large construction projects project principals often lack the ability to mentally visualize project specific risks, and, thus, they are, frequently, not able to make adequate decisions to mitigate these risks. A visual representation with 4D models - 3D models of a construction design combined with a construction schedule – is a way to overcome this problem. This paper presents first explorative findings of using 4D models to support risk managing activities of project principals from a case study we conducted on the Rotterdam Railway station project, a high risk 620 million Euro construction effort in the center of Rotterdam. The paper outlines the existing risk management process on the project and shows how we assessed ways to visualize project risks with 4D models.

Keywords: 4D, visualization, risk management, AEC work routines, design

NTRODUCTION

On large construction projects it is of key importance for project principals to understand project risks well. To support such an understanding, traditionally, project managers communicate project risks in a tabular form as risk inventories and explain risks in more detail using written reports, Gantt charts, and sketches. However, due to the complexity of large construction projects that integrate multiple design disciplines, multiple sub-projects, and sub-project interfaces, across different stages of construction these tools do not allow project managers to quickly visualize and explain project risks, their location on site, when they might occur, and their possible implications on the projects outcome to the project's principal.

4D models are three dimensional representations of the construction design combined with the construction schedule that show all stages of the construction process in time and space. 4D models capture both the temporal and spatial aspects of schedules and communicate schedules more effectively than a Gantt chart (Eastman et al., 2008). In the past, project managers used 4D models to

evaluate and analyze design constructability, sub-contractor coordination, and schedule optimization (Hartmann, 2008). Theoretically, project managers can, additionally, use 4D models to visualize project risks and to show what the effects of identified and evaluated project risks may be.
To explore the practical feasibility of this theoretical possibility, we conducted a case study during which we applied 4D models for risk visualization to assess the possibility to clearly visualize risk information within a 4D model. This paper reports the lessons learned from this case study and, in this way, empirically assesses the utility of 4D modeling methods to visualize risks to support risk communication towards the project principal.
The paper is structured as follows: It starts with a theoretical introduction about project risk management and 4D visualization. Afterwards, it briefly introduces the case study research methodology we used during this research. The main part of this paper then focuses on describing the different possibilities of visualizing project risks that we explored on the case project. The paper closes with a short discussion about possibilities for researchers, but also practitioners, to build on the work we present in the future.

PROJECT RISK MANAGEMENT

On construction projects, it is important that project teams assess the chance that project risks occur and the impact of project risks if they occur in a systematic way using formal risk management methods (Well-Stam et al. 2008, p.13). The goal of such risk management methods is to (1) continuously, make risks explicit and control risks, to ensure everybody has the same and complete picture of the risks, (2) approach risks in a pro-active way, (3) and to consciously approach risks and determine control measures (Well-Stam et al. 2008, p.57). Different risk management methods exist (see for example Well-Stam et al. 2008, Forbes et al. 2008, Choi et al. 2004, Smith 1999), however, the key steps of each of these methods are similar: Figure 1 shows a typical outline of the steps of such a formal risk analysis method. During the risk management process, it is, additionally, important to distinguish between the linear risk analysis process (Figure 1), used to determine the chance of occurrence and the impact of a risk, and the cyclic process of risk management and mitigation (Figure 2), used for implementing control measures and monitoring the effect of these measures.

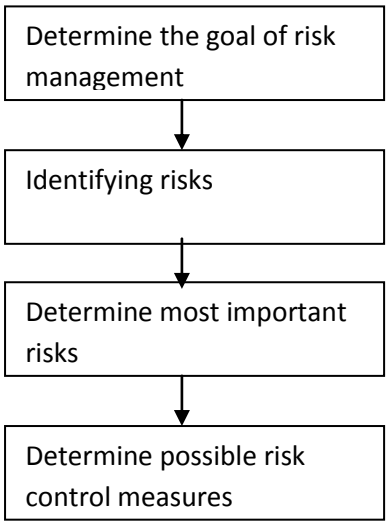

Figure 1: *Steps during risk analysis (Well-Stam et al. 2008)*

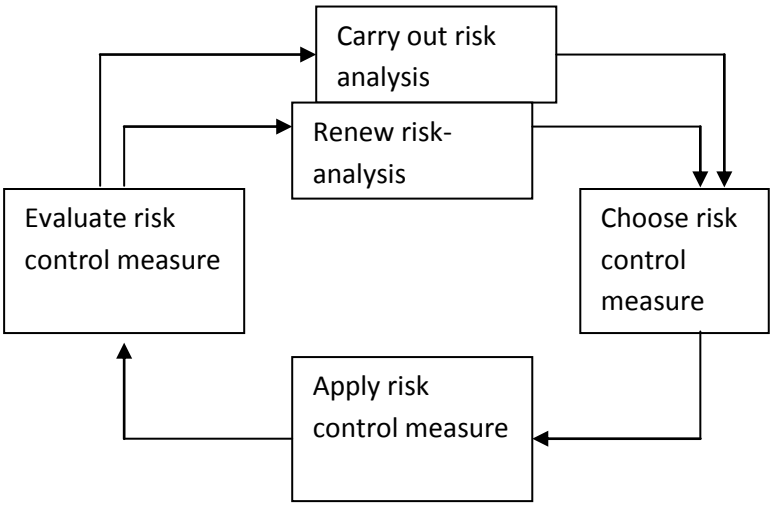

Figure 2: *Typical Risk management cycle (Well-Stam et al. 2008)*

One important part during every risk management exercise is the communication of risks towards the project principal to ensure that the principal has a good overview of the projects risks and is able to decide on control measures to choose. However, project managers oftentimes fail to do so because the project principal may lack the skills to understand and makes sense of the documents that project managers usually use for project risk management, such as construction drawings, GANTT charts, or technical risk reports. 4D models with their potential to clearly visualize project risks can help project managers to, more effectively, communicate and exchange the needed information.

Visual representations of project designs can help project teams to articulate, exchange, and understand complicated design ideas (Ewenstein and Whyte 2007). Traditionally, project managers use 2D drawings, Gantt-charts, and sketches to clarify the construction design, but these ways of visualizing do not integrate the temporal or spatial dimensions. 4D models (Hartmann et al. 2008) are a form of visual representations of project designs that also account for the temporal aspect of how project teams plan to construct the project according to construction schedules. Project managers have already applied 4D models on a number of projects to communicate design ideas to decision makers. Using this approach, project managers were able to significantly improve the communication in meetings (Hartmann et al., 2008). 4D enables to simulate the planned construction of a design. Within the 4D model it is possible to, explicitly, indicate the location and possible time of occurrence of a risk. Therefore, we expect that 4D models will be very helpful for project managers to communicate project risks to project principals as a part of the risk management process. The next section describes the design of our case study in more detail.

RESEARCH METHOD

To explore the feasibility of this idea we conducted case study research on the 'Rotterdam Centraal' construction project, a 620 Million Euro construction effort in the center of Rotterdam. We chose this high scale project because of the project's complexity. Therefore, we expected enough need for, and thus potential benefits from, risk visualization. To reduce the scope of the research activity we decided to focus our explorations of the risk management practices on the final design phase of the construction of the underground, bicycle storage sub-project. We chose this specific sub-project because project managers of the project expect significant risks during the construction of the storage. They had this expectation mainly because of the many interfaces with other sub-projects at the Rotterdam Railway station area.

During the case study, the first author used ethnographic action research (Hartmann et al., 2009), an iterative research methodology to explore new technologies within project contexts. Figure 3 summarizes the different steps of the iterations of the action research process. Ethnographic action research is an approach that tries to improve the implementation and development of technologies by understanding the experiences of project team members and the work routine of practitioners: how practitioners at the project create and exchange risk information and what artifacts they use to do so. "This understanding can be used to implement and customize information systems under special considerations of local project culture, instead of trying to force the use of a ready-made system" (Hartmann et al. 2009). Ethnographic action research enabled us to focus on understanding the dynamics present within single settings (Eisenhardt 1989). We were able to observe how practitioners use the 4D model while, at the same time, develop new ways of visualizing risk

information with 4D models. The rest of this section describes the data collection methods we used during each of the steps of the ethnographic action research in detail.

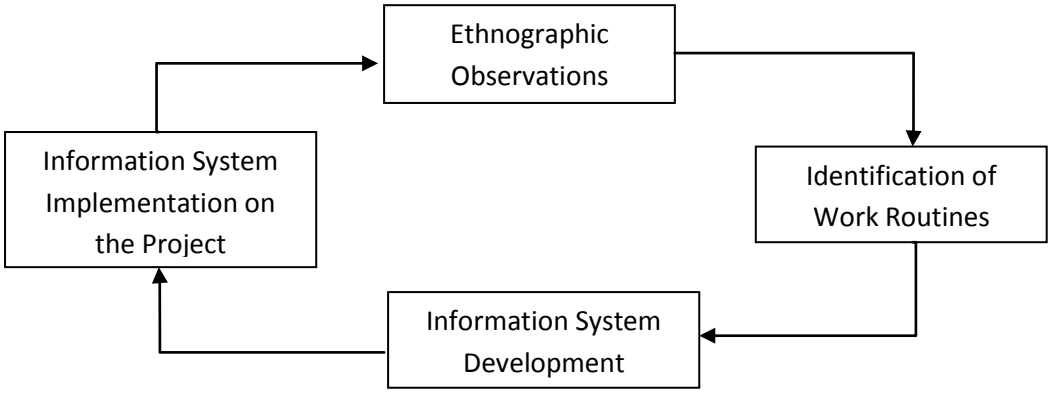

Figure 3: *Ethnographic action research cycle (Hartmann et al. 2009)*

At the start of the research effort the first author read project-specific documentation, such as the project plan and the risk related start-up report. These documents gave him an overview of the projects organizational structure and helped him to identify the project organizational context and the project's formal work routines. The first author took open-ended interviews with the project manager, the project principal, the project planner, and design managers to become familiar with the project participants and get an in depth understanding of the work routines of the project organization. During these interviews the first author, e.g., discussed the current usage of 3D/4D visualizations at the specific case project. Furthermore, the first author asked the participants to indicate whether or not they saw possibilities for using 4D models to visualize project risks.

In the first step of the action research process, the first author observed the usage of the visualization model during 5 team meetings. To keep record of these findings the first author took notes during the meetings. In his notes, the first author, for example, recorded which members of the team interacted with the current visualization model (an interaction is a request of a team member to the visualization model expert to visualize certain aspects of the design) or how project team members already explicitly or implicitly used the model for risk management activities. From these observations the first author described how the visualization model is currently used at the company.

Based on the findings from these ethnographic observations, the first author then used a commercial 4D software package to visualize different risk related information. Using this 4D risk model the first author assessed the functionality of the model and different ways to visualize risks by demonstrating the 4D model to the project team members and the project principal in demonstrations. In the next sections, we will describe our findings using to the ethnographic research cycle as an outline: First, we explain the project specific organizational context and the current usage of 4D models. Then we describe the most important risk management related roles and work routines of project participants. Finally, we describe how we developed a basic 4D risk model and assessed the functionality of different types of risk visualizations.

OBSERVATIONS: ORGANIZATIONAL CONTEXT AND 4D MODEL USE

Figure 4 illustrates the formal organization of the project. Important positions, with respect to the scope of this paper, are the project manager and the risk specialist. The project manager was responsible for successful risk management at the sub-project level. In particular, he was responsible for a proper application of the risk management cycle and for communication of the project risks towards the project principal. The project manager and the project principle indicated that they communicated on a weekly, informal, basis. The risk specialist was responsible for the risk analysis and for organizing collaborative risk management activities, such as the so called 'risk sessions'. At the beginning of the final design phase, the risk specialist created the risk inventory that contained all assessed information on the identified risks of the sub-project. Then, during the final design phase, the risk specialist kept track of the design by, informally, discussing the progress with other practitioners and attending project control meetings. Additionally, the risk specialist noted the progress of risk control measures within the risk inventory. Finally, at the end of the design phase, the risk specialist will fully renew the risk inventory.
During the risk management process both the project manager and the risk specialist used the input from multiple disciplines, such as public space, building engineering, and construction.

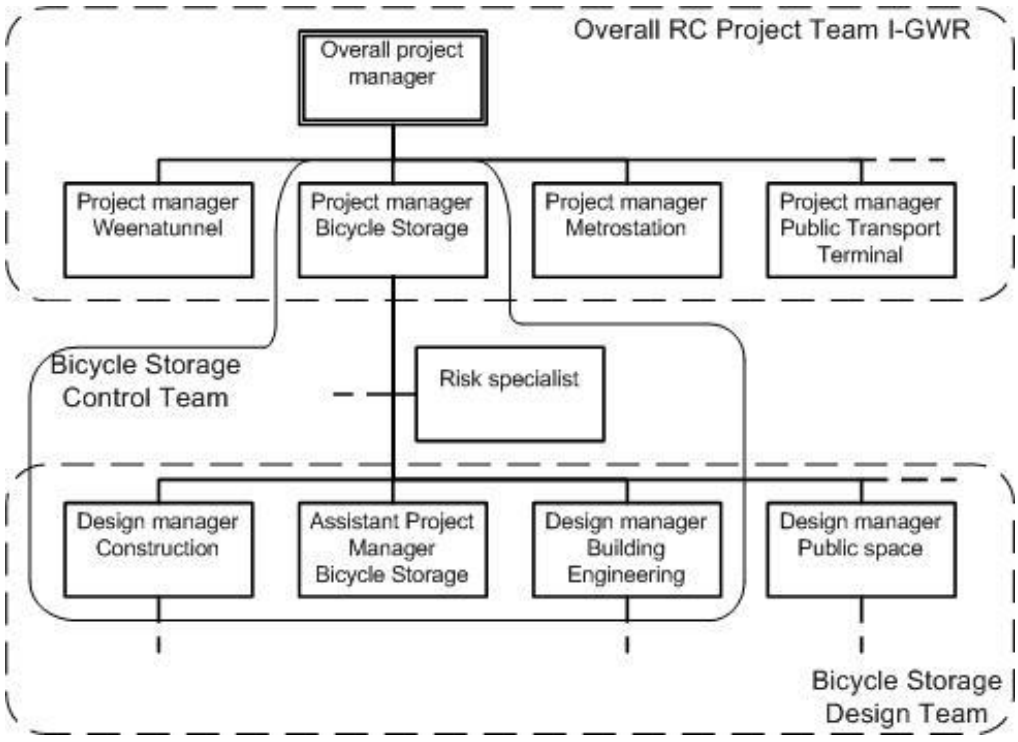

Figure 4: *organizational chart, showing the positions described in this paper.*

Risk management

Risk management is applied at sub-project level. For every sub-project a risk specialist creates a risk inventory which he updates once every three months, depending on the phase of the project and the projects complexity. At the bicycle storage project the risk management process started with a start-up session and will finish with the renewal of the risk inventory at the end of the final design phase. All the bicycle storage project participants were invited to participate in the start-up session. Before

the meeting, the risk specialist asked the participants to describe the five most sub-project threatening risks. The risk specialist wrote a risk start-up report and generated a risk inventory, containing the risks that project participants identified during the risk start-up session. This risk inventory is the main risk management artifact for the sub-project's risk control activities, containing the identified risks, the evaluated risk information, and possible risk measures.

3D/4D model usage within the project team

The project team already used 3D models of the bicycle storage during special monthly team meetings, together with the representatives of the project's principal. A 3D/4D modeler built this model based on the 2D design drawings of the project. During these meetings, the project team used the 3D model, in particular, for walkthroughs to review whether the specific designs are socially acceptable and usable by the public. During these meetings the 3D/4D modeler annotated the findings on specific viewpoints, which he saved and integrated as images within the meeting minutes. The 3D/4D modeler also used the 3D model to visualize the projects design during the design team meetings of the bicycle storage, but at these meetings the meeting participants did not use the 3D model. The design team members used their own 2D drawings to explain the design. Meeting participants did not use 4D functionality during meetings of the bicycle storage project to explicitly visualize 4D construction phases to the project principal.

Next to meetings focusing directly on the bicycle storage sub-project, project managers discussed the interfaces between the different sub-projects in meetings focusing on the overall project. In these meetings the project managers used the 4D model without specific risk objects to visualize the progress of the construction of the overall 'Rotterdam Centraal' project. Before these meetings the 3D/4D expert established a few viewpoints – specific views, saved within the model - to enable to quickly navigate to the topic of discussion in the respective meeting. During these meetings the practitioners requested the 3D/4D modeler to show specific moments of construction and they were more actively engaged with the model. They, for example, made annotations on the interactive whiteboard during discussions to explain the impact of a change to each other.

POSIBILITIES TO VISUALIZE RISKS IN 4D

After observing the existing routines on the project, the first author explicitly assessed different ways to visualize project risks using 4D models together with the 3D/4D modeler. In general, these 4D visualizations should enable the project principal to understand (1) the location of a risk within the models main interface, (2) the time-frame when a risk may occur within the model, and (3) contain risk-specific information. Together with the 3D/4D modeler we identified different ways to visualize risk information that fulfill some or all of these requirements: Saving risk related annotations on viewpoints, inserting tags, and adding risk indicator objects with pop-ups. Table 1 summarizes the capabilities of these three risk-visualization types and their capabilities. The rest of this section defines and explains each of the risk-visualization types in more detail.

Risk indicator type	Indicate location	Indicate time-frame	Contain risk-specific information
Viewpoint	x		x
Inserting tags			x
Risk object	x	x	x

Table 1: *4D risk visualization types and their capabilities*

Viewpoint with annotations

A viewpoint is a saved specific view from a certain position within the 4D model. Project managers can easily define viewpoints with added annotations using the functionality of the 4D software (see figure 5). On the viewpoint the project team member can annotate and draw to explain what is seen. Thus, project team members can easily use this 4D risk visualization type to articulate, exchange, and explain risk related information during a 4D model demonstration to the project principal. Annotations linked with these viewpoints can contain any form of textual or drawn information. However, saved viewpoints are only a snapshot of a specific location in the time-dimension. They cannot be linked to activities within the project schedule. Therefore, viewpoints cannot effectively indicate when a risk occurs within the construction progresses.

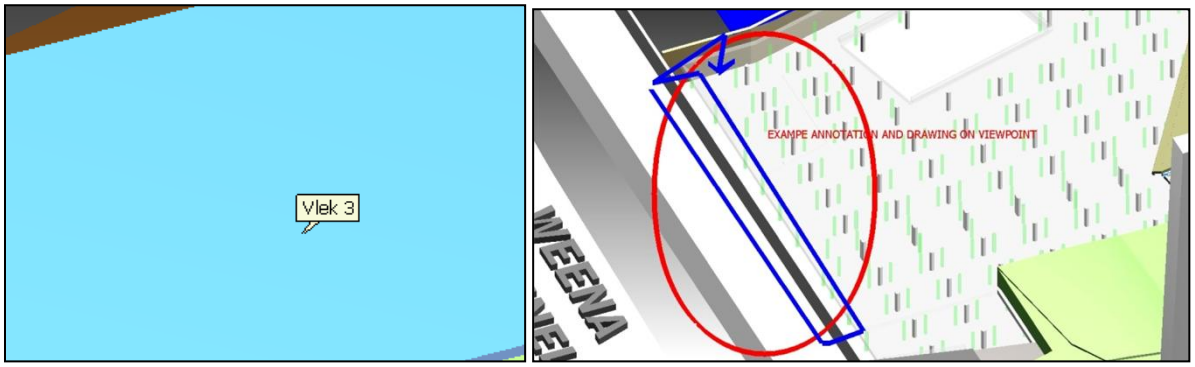

Figure 5: *Example of (left) a tag and (right) a viewpoint with annotations.*

Tags

Tags are inserted textual leaders within the models interface (see figure 5). These tags can contain risk descriptions, or other types of risk information. Project managers can easily add textual information to tags. However, tags are not very effective in visualizing the location of risks because they are relatively small. Therefore they can easily be overseen within the models interface. Additional, like viewpoints, tags are static objects that cannot change their appearance dynamically. They cannot be linked to activities within the construction schedule. Overall, we think tags are unsuitable to visualize risks within the model.

Risk specific objects

3D/4D modelers can add specific objects that represent a specific risk (Figure 6). These risk specific objects can be linked to specific tasks in the construction schedule. In this way, risk specific objects

integrate the visualization of risks at a specific time and location within the 4D model. The 3D/4D modelers can give risk objects every possible shape and color. Furthermore, 3D/4D modelers can integrate risk information from the risk inventory as a property of the risk object. It is possible to directly link this specific information to the official risk inventory. In this way, 3D/4D modelers can easily renew the shown risk information in case the risk specialist changes the information within the risk inventory. Functionality of the 3D/4D software allows that risk information can pop-up within the main interface at the moment the project manager or project principal moves his mouse pointer over the object. Any added textual risk-specific information, e.g. the risk description and inventoried suggested risk control measures, becomes visible once the pointer moves over the risk object.
In summary, our theoretical evaluation of risk visualization types shows that only risk specific objects fulfilled all of the requirements for a 4D risk visualization object. Therefore, we chose to demonstrate and test risk specific objects in the implementation step of the action research cycle.

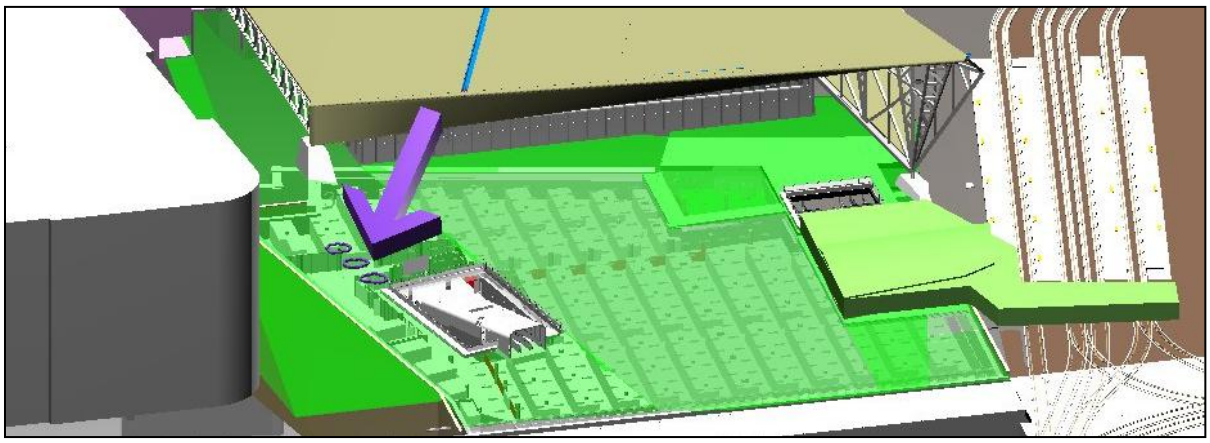

Figure 6: *Example of risk indicator objects, this specific set of objects indicate the location(s) where two separate designs might clash.*

IMPLEMENTATION: DEMONSTRATIONS

Multiple risk objects – e.g. arrows, contours, and clouds (figures 6 & 7) - where designed by the 3D/4D modeler, based on sketches from the first author. The first author demonstrated these different types of risk objects within a team meeting, to individual project team members, and to the project principle to determine the needed characteristics of effective risk visualization objects.

First, a demonstration in front of the control team meeting was given with the 4D model. Six people attended this meeting. During this demonstration the practitioners actively discussed the presented model. The usage of 4D was new for most attendants. Therefore, the discussion mostly dealt with the design and possible usage of the 4D model itself. Practitioners also discussed some of the demonstrated risks. The added textual information appeared to be not readable within a meeting setting. Further, it appeared that the 4D model gave the practitioners a better feeling for height. Afterwards all practitioners indicated in a short questionnaire that they found the risk objects clear. Five out of six practitioners indicated that presenting risks within a 4D model could improve their understanding during discussions in team meetings. Although, 4 of them indicated that the level of detail of the 4D model should be more appropriate.

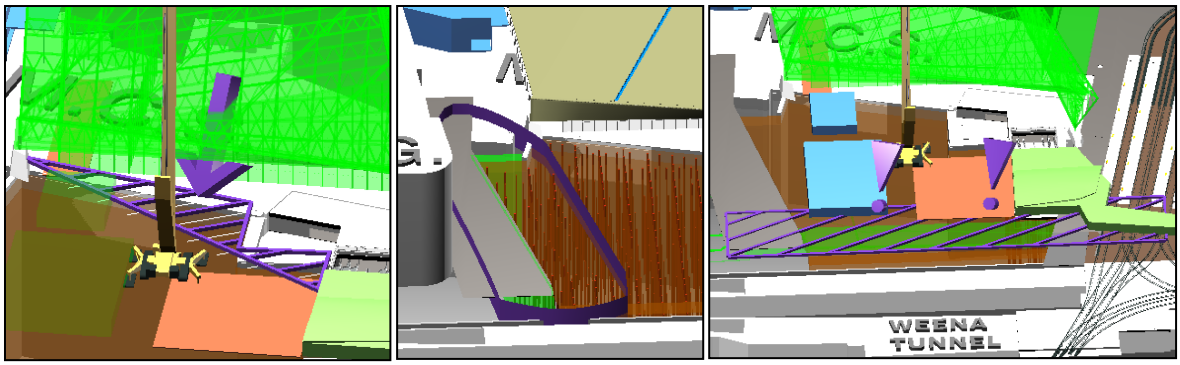

Figure 7: *Different types of risk indicator objects, (left) an arrow with a hatched surface, (middle) a contour, (right) a hatched area with warning signs.*

Second, the 4D model with risk objects was demonstrated to 5 individual practitioners to measure their personal opinion. These demonstrations took between 15 and 30 minutes each. Afterwards each practitioner filled in a questionnaire. We clearly found from first discussions before these demonstrations, while designing the risk objects, that a risk object has two, distinct, functions within the 4D models interface. (1) Attract the attention to a risk (visibility), and, (2) Indicate the specific location where a risk may occur. Therefore, the first author asked practitioners to indicate wither or not they found the shown specific risk objects suitable at these two points. Table 2 summarizes our findings from the demonstrations with individual practitioners.

Risk object	**Visibility**	**Indicates location**
3D arrow	4	3
Warning sign	1	-
Cloud	2	3
Contour	-	-
Hatched surface	2	3

Table 2: *risk objects and cumulated score from 5 demonstrations.*

We found that most practitioners preferred an arrow to be the best risk object shape, in some cases complemented with a hatched surface or cloud(s) (figure 6) to indicate the specific location of the risk more precise within the models interface. However, practitioners indicated that the pop-up with textual risk information appeared to be visible relatively short. Further, they indicated that risk objects generated a high information density within the model. That made it harder to interpret the model, maybe also due to the newness of the usage of 4D models. Last, we found that it is of vital importance for the 3D/4D modeler to design risk objects in such a way that the risk object does not look like a part of the design, or a construction activity, within the model. Therefore they found the contour was seen as unsuitable.

CONCLUSION

This paper presents the results of a case study that assessed the possibilities to visualize risks within 4D models. This paper describes how the project team of the project applies risk management and how it uses 3D/4D models to support the risk management processes. During the case study we were able to identify two ways with the potential to visualize and explain risks within a 4D model. Project managers can directly visualize information by making annotations and saving viewpoints within the model. But, this way of visualization cannot be part of the 4D simulation, as viewpoints can only be snapshots of the model. Additionally, 3D/4D modelers can explicitly indicate the location of risks within a 4D model by adding risk objects. We found that most practitioners preferred an arrow to be the best risk object shape, in some cases completed with a hatched surface or cloud(s) (figure 6). From demonstrations with the model with these risk-specific objects we found that the model can already help the project team to present, discuss and explain risks within a 4D construction simulation during a meeting. It contributed to a meaningful discussion. Although, we found that it was not yet possible to effectively present textual risk information due to software limitations. And, further, risk objects may sometime generate a high information density within the model, making it harder to interpret the model.

In the long run, this research is a step to help project teams to visualize risks with 4D models. This can help the project manager to discuss risks. Such an explicit visualization of risks will contribute to the first goal of risk management: The clear visualizations will help to continuously make risks explicit and will ensure everybody has the same, and complete, picture of the risk.

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