# Changing Scheduling Purposes and Evolving 4D-CAD Models: A Study of Planning and Realization in a Utility Project

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## ABSTRACT

This research explores scheduling purposes and related 4D-CAD requirements during planning and realization of a 900m sewer line construction project. We used an ethnographic-action research approach to investigate how changing scheduling purposes influence 4D-model setup. To this end, we implemented 4D-CAD in a real-life setting, iteratively improved the model, and observed how it was used by practitioners. Observations show that in the planning stage scheduling concentrates on task identification, resource allocation and stakeholder communication, while jobsite scheduling focuses more on operational task dependencies, delay mitigation and site logistics. These changed purposes eventually impact required detail and focus of 4D-CAD models.

## INTRODUCTION

Urban utility infrastructure projects significantly impact surrounding neighborhoods. They are constrained by strict temporal and spatial boundaries and challenge contractors when aligning sequential construction activities, creating traffic accessibility plans and optimizing site logistics. Alignment of such plans often occurs during meetings. Here, paper-based designs and schedules are manually discussed and integrated. To support this cumbersome task, construction managers could make use of 4D-CAD. Although 4D-CAD is used more frequently in the built environment, its application in utility projects – especially on the jobsite - still seems problematic.

To better understand this phenomenon, this research investigates how differences between 'work planner scheduling' and 'jobsite scheduling' impact 4D-CAD model characteristics. We therefore conducted ethnographic action research on a 900m sewer-line reconstruction project. We iteratively developed, improved and evaluated the project's 4D-CAD model together with practitioners. Additionally, we traced how changing scheduling purposes necessitated adaptations to the 4D-CAD model. Our findings show that by gradually adapting planning stage 4D-CAD models to the needs of the realization stage, practitioners can better align 4D-CAD models with jobsite scheduling purposes.

This paper is outlined as follows: we first describe how shallow subsurface infrastructure projects can benefit from 4D-visualizations. Next, we provide a case description and outline how planning and jobsite purposes of scheduling influence 4D-CAD characteristics. We end with a discussion and conclusion.

## THEORETICAL BENEFITS OF 4D-CAD

Construction process visualization tools such as 4D-CAD integrate three dimensional design models with the project's (fourth) time dimension. By visualizing how the project's space actually "transforms over time during construction" (Webb, Smallwood, & Haupt, 2004), "practitioners can virtually rehearse a construction process as it would be actually built"(Koo & Fischer 2000). As demonstrated by various researchers, 4D tools support the development of an intuitive understanding of a project (Heesom & Mahdjoubi 2004) to communicate and review designs, detect clashes, and review project progress (Mahalingam, Kashyap, & Mahajan, 2010). Within the civil engineering domain, the tool supports tasks such as constructability reviews (Hartmann & Fischer 2007), construction operation analysis (Hartmann, Gao & Fischer 2008), construction planning, resource management and site space utilization (Wang, Zhang, Chau & Anson 2004). Although most research took place in the domain of facility and housing projects, also horizontal projects can benefit from 4D-CAD tools (Zanen, Hartmann, Al-Jibouri & Heijmans 2013).

Our research follows this lead and explores the use of 4D-CAD in the domain of subsurface utility construction projects. While first implementing 4D-CAD in this domain, we observed that jobsite implementation of 4D was still problematic. Surprisingly, this contrasted earlier findings about effective use of 4D onsite (Chau, Anson & Zhang, 2004; Mourgues, Fischer & Hudgens 2007). To better understand the root and cause of this observation, we analyze how purposes of scheduling change as the project moves from its planning to realization stage, and how these changes necessitate adaptations to the project's 4D-CAD model.

## RESEARCH METHOD

To investigate the extent to which 4D-CAD models match the purpose and requirements behind the planning practices of work planners and jobsite managers, we used the ethnographic action research approach (Hartmann, Fischer, & Haymaker 2009). In this approach, researchers iterate between identifying existing work cultures and practices, designing and implementing an intervention (e.g. a 4D-CAD model), and evaluating how this changes practice. The steps allow to incrementally improve both adopted 4D-tools and work practices.

Our case comprised of the renovation of a 900m sewer-line in a Dutch residential area. Stakeholders in the project team were representatives of a small engineering consultancy, two representatives of the municipal client, and three project members working for the main civil contractor. During an eight month period, the team allowed us to observe and support project planning and execution tasks with 4D.

To develop a 4D model for this project, we obtained 2D-CAD drawings from the engineering consultancy firm and retrieved the contractor's master schedule. To convert existing 2D-CAD drawings into 3D-models, we first identified relevant construction objects. We then made educated guesses of each object's height-dimension, and subsequently extruded them to create 3D-solids. We integrated the resulting 3D-model with the project's work plan schedule.

Shortly after we developed the first version of the 4D-CAD model, we organized two meetings with the contractors' project coordinator. Here, we reflected on the 4D-CAD model and its underlying schedule and discussed whether the model could meaningfully support coordination tasks. Later, when the project progressed from planning to its realization stage, we implemented the 4D-CAD model during three multi-stakeholder coordination meetings. Here, we discussed with practitioners how the 4D-CAD model should be adjusted or updated to fulfill jobsite scheduling needs. We recorded our meetings in audio and video and also registered all changes made to the 4D-CAD model in our 4D-log file.

While analyzing our qualitative data we focused on the identification of purposes in scheduling practices. From the discussions with the project coordinator, we for example identified statements that explained purpose and setup of early stage scheduling. Besides, we also extracted from our 4D-log which changes to the 4D-CAD model were made during the three jobsite meetings. Finally, we compared the identified schedule requirements and 4D-CAD model characteristics for these distinct project lifecycle stages (i.e. planning and realization). These outcomes enabled us to globally describe and explain the required 4D-CAD model changes during the project's life cycle.

## RESULTS

In this section we explain how scheduling requirements consecutively influenced the setup of the 4D-CAD model. We contrast the distinctive purposes in scheduling and their corresponding 4D models in this paragraph.

**Identified purposes of early stage planning and jobsite scheduling.** We categorize work planning and realization stage scheduling purposes along the categories process orientation, communication, and improvisation. These will be elaborated in this section: First, during work planning, we observed how the schedule was used to globally orient on necessary work processes and their durations. In grasping the project's content and scope the project coordinator, for example, used contract documents to extract the main packages of work tasks. Here, a schedule allowed him to hierarchically break packages down into an overview of tasks.

Further, the work planner had to identify and allocate resources along the project's timeline. Based on the received project deadline, the work planner therefore developed a schedule and the allocated tasks and resources needed to complete the project within the allowed time span.

We also observed how the project manager used a schedule to communicate with the client about construction plan feasibility. Here, the work plan schedule was considered merely as feasibility plan rather than an accurate, robust process description that could be used for daily coordination. Finally, an identified schedule purpose was to explain plans to external stakeholders. In our project, for example, the schedule was printed out and discussed with residents during an early stage stakeholder consultation.

Second, during our discussions with the project coordinator and during our three construction project meetings we additionally identified purposes of jobsite scheduling. During the coordination meetings we observed that the manual schedule was used for process orientation: the project team compared the as-built with the as-planned situation. To support this task they consulted the original work plan schedule. As this first schedule did not describe daily construction tasks in sufficient detail, practitioners could only use it to roughly estimate whether the as-built situation onsite matched the original work plan. As the project coordinator explained, the work plan schedule could often not adequately support an evaluation of smaller, yet critical, tasks such as installing dewatering drains or sewer-line demolishing, since such tasks were usually left out of a work plan.

Another observed jobsite scheduling purpose was to support evaluation of possible construction delays and delay mitigation alternatives. This process orientation purpose required jobsite schedules to include tasks and detailed predecessor relations. Such information was not yet explicitly included in the work plan schedule, so it had to be added manually to update the 4D-CAD model.

Yet another scheduling purpose concerned the creation of site logistic plans. To this end, spatial occupation and constraints corresponding to construction tasks had to be extracted from the work plan. During our modelling efforts, however, such information appeared not always available.

Further, we observed how jobsite scheduling had a communicative purpose: practitioners used the schedule to communicate traffic rerouting issues within the project team. Although they argued that 4D-CAD could help them with such coordination tasks; this was not possible initially, since practitioners did not specify any traffic or logistics-related information in their original work plan schedule.

Finally, improvisation related discussions took place around sequencing and work directions decisions. One jobsite discussion, for example, focused on the sequence and working direction of repetitive sewer placement and paving tasks. In the work plan schedule, this sequencing information was not explicitly captured. Instead, most of the smaller repetitive tasks were only scheduled as large aggregated activities.

The identified scheduling purposes are summarized and contrasted in Table 1. From this table, it can be observed that work planner’s logic is mainly related to task identification, resource allocation and global stakeholder communication, while jobsite coordination discussions center on technical task dependencies, delay mitigation and improvisation.

**Table 1. Comparison of work planning and jobsite purposes for scheduling during planning and realization of the utility project case.**

| *category* | *Work planning scheduling purposes* | *Jobsite scheduling purposes* |
|---|---|---|
| Process orientation | • To translate tasks from contract documents into as task overview<br>• To identify and allocate required resources to timeline of project | • To evaluate daily construction progress<br>• To evaluate construction delay & delay mitigation plans<br>• To assess site occupation create logistics plans |
| Communication | • To globally show planned project activities to the client<br>• To globally communicate project phasing to external stakeholders | • To communicate traffic rerouting alternatives |
| Improvisation | | • To make ad-hoc decisions on sequence and working direction |

**Consequences for 4D-CAD model usage.** The previous comparison illustrates that schedules have different purpose during work planning and realization stages. When considering the changing scheduling purposes in the light of 4D-CAD development, this means that early stage schedules and related 4D-CAD models likely necessitate updates during the project. Formulated negatively, models seem unlikely to be used to their full potential during jobsite meetings when they are still based on work planning purposes.

We observed this in our project when we developed and implemented 4D-CAD models together with practitioners. To customize the work planning based 4D-model towards jobsite purposes, several changes had to be made. For example the initial plain bar-chart schedule had to be converted into a more detailed chart that explicitly included additional details such as task dependencies and constraints. Second, to support progress discussions during jobsite meetings, we adapted the 4D-CAD model so that it better visualized progress and delay in main construction tasks. To this end, practitioners identified critical construction tasks and provided productivity rates that allowed us to break down the schedule and 3D-model into more detailed project elements. Finally, we observed that the work planner-based 4D-CAD could not effectively support jobsite discussions related to working directions and sequencing. To solve this problem, practitioners suggested to increase the detail of the 4D-CAD model and to reconfigure object sets so that they could be clustered and ordered in the actual construction sequence. In table 2 we provide an overview of the changed characteristics of the 4D-CAD model and its underlying schedule.

**Table 2. Comparison of derived 4D-CAD characteristics during planning and realization of the utility project case.**

| *Characteristics of work planner 4D-CAD model* | *Characteristics of jobsite 4D-CAD model* |
|---|---|
| Based on plain bar-chart | Based on chart including task dependencies and constraints |
| Based work breakdown structure extracted from contract documents work planner 4D-CAD model | Further details WBS to describe daily construction process (as-planned, as built) |
| Based on contractors' productivity standards | Based on empirically observed productivity |
| Globally visualizes the phases within the project's schedule | Visualizations include detailed sequence and work direction |
| Clusters 3D-objects in larger-sets | Breaks down 3D-object sets |

## DISCUSSION

This study shows how changing scheduling purposes necessitated adaptations to our project's 4D-CAD model. Of course, our findings are not without limitations. As they are based on a single project, it is uncertain whether our results are applicable and generalizable beyond this context. To further test the generality of our findings, further studies are hence needed. Such studies can additionally aim to further validate identified scheduling purposes and changing 4D-CAD characteristics.

Another lead for future research concerns the technical steps of 4D-CAD modelling. Future research can, for example, spell out the required steps to build 4D-CAD models. Also, to facilitate 4D-CAD model evolution, we also suggest that future research explicates and illustrates in greater detail how 4D-CAD models evolve to meet changing practical scheduling requirements.

Finally, manual updating of 4D-models is time-consuming. Fortunately, automation technologies such as sensor laser scanning (Golparvar-Fard, Peña-Mora, & Savarese 2011; Turkan, Bosche, Haas & Haas 2012), laser tracking devises (Wu, Lu, Mao & Shen 2013), and imaging processing technologies (Kim, Kim & Kim 2013) can support automation of this process. Future research could be directed at effectively integrating our identified scheduling purposes with existing methods for automatic 4D-CAD updating.

## CONCLUSION

This research investigates implementation of 4D-CAD on an eight-month, 900m m utility reconstruction project. We identified how scheduling purposes that underlie 4D models change during planning and realization stages, and show how 4D-CAD models need to be adapted accordingly to effectively support jobsite meetings.

Based on our ethnographic action research efforts, we found that early stage scheduling practices, including steps as task identification, resource allocation and stakeholder communication, were mainly explorative and aimed to show the overall project feasibility. This resulted in an early stage global schedule based on semantics and task descriptions implied by contract documents. When the project moved to the execution state, changes to the 4D-CAD model had to be made to re-align the earlier work planning-based 4D-CAD model with more technically oriented scheduling issues on the jobsite.

Our findings contribute to current 4D-CAD research in two ways. First, our empirical research in smaller-sized urban construction projects extends current 4D-CAD studies that merely focus on facility and large infrastructure projects (e.g. Russell, Staub-French, Tran, & Wong, 2009; Zhou, Ding, & Chen, 2013). Additionally, by highlighting changed scheduling purposes and corresponding 4D-CAD model requirements, this longitudinal study is first in exploring necessary aspects of 4D-CAD model evolution.

Findings also have implications for practice: By showing how 4D-CAD model requires changes during the project life cycle this study helps 4D-modelers and BIM-experts to maintain the practical applicability of the models that they develop.

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