Comparing Mindfulness in Manual and 4D Supported Coordination Practices

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ABSTRACT
This research investigates the role of 4D visualizations in enhancing mindfulness in construction project coordination. We introduce the mindfulness concept - defined as capacity to detect (potential) operational errors and take corrective action – to make a comparison of two distinctive coordination practices. To this end, manual and 4D supported coordination three cases of three inner city reconstruction projects were examined. Observations were structured using five principles underlying mindfulness. Four of these principles supported our hypotheses that 4D allows managers to better anticipate and contain errors. We conclude by describing how 4D creates focus on operational interdependencies (1), helps to detect potential conflicts (2), increases resistance to simplifications through detailed visualizations (3), and enables development of containment strategies (4). Such practices eventually reduce conflicts, delays, and cost overruns, enhancing the reliability of coordination processes.

INTRODUCTION
Urban infrastructure reconstruction projects irrefutably impact their surroundings. Positioned in the midst of scarce public spaces, these projects are often notorious as they block main traffic routes, limit access to facilities, cause noise and vibrations, and create potentially unsafe situations. To minimize the burden on stakeholders, authorities therefore confine construction space and impose strict deadlines. These tight project conditions challenge project clients and contractors in managing their construction activities: Within a predetermined sequence, the various parties need to, for example, demolish existing infrastructure, conduct excavations, install cables, pipes, and sewerage, set-up public lightning, and repave road surface.

To streamline construction tasks utility companies, municipalities, and their contractors commonly spend significant time on planning and scheduling. They organize coordination meetings to integrate their various interrelated construction tasks. During the meetings, they aim to develop a reliable overall construction plan that anticipates potential problems, conflicts and clashes, provides possible solutions, and integrates these within a realistic construction schedule. In current practice, such construction plans are often developed through verbal discussions and manual integration of paper-based drawings and schedules. Unfortunately, as reality of cost and time overruns shows, this practice seems not to overcome practitioners’ difficulties in cognitively grasping important dependencies and
management interfaces. This complexity often results in less reliable (suboptimal) plans that overlook overall construction problems. Site supervisors and managers therefore often troubleshoot through improvisation, re-planning and mobilization of additional resources. As a consequence, project budgets and schedules overrun, subsequently frustrating stakeholders and increasing public expenditures.

This study assumes that project managers could enhance reliability of their planning processes if they pursue mindful behavior in their current coordination practices. Weick, Sutcliffe et al. (1999) define mindfulness as “enriched awareness for discriminatory detail and a capacity [to take] action” to correct for unexpected events. In other words, organizations establish mindfulness through effective anticipation and containment of unexpected events. There are five lower-level principles to help organizations in reducing unwanted events such as holdups and overruns (Weick, Sutcliffe et al. 1999; Weick and Sutcliffe 2007). According to these principles, anticipating organizations are pre-occupied with potential failures (1), are sensitive to complexities and developments in ongoing operational tasks (2), and are reluctant to simplify interpretations (3). Organizations effectively contain when they incorporate resilient decision making structures (4), and defer to expertise in periods of problem solving (5).

This study hypothesizes that 4D tools can improve mindfulness in planning. 4D tools combine 3D-CAD construction models with project schedules. They graphically represent the relationship between construction space and a project schedule by visualizing the transformation of that space over time (Webb, Smallwood et al. 2004). These visualizations can, for example, help managers to develop detailed understanding of operational complexities and to identify potential problems (Heesom and Mahdjoubi 2004). Further, such tools allow managers to create and evaluate alternative construction plans. We argue that these benefits help organizations in following the five principles of mindfulness, and therewith enhance mindfulness of their manual planning practices. To support this argument, we compared a manually coordinated utility project with two projects that implemented a 4D visualization tool. We compared coordination on these projects and show instances of enhanced mindfulness on the 4D supported projects.

This paper is structured as follows: first, we elaborate on coordination of urban infrastructure projects and the concept of mindfulness. We then briefly draft the theoretical argument that 4D visualizations can enhance mindfulness. Next, we describe how we used the principles of mindfulness to compare the distinctive coordination practices we observed. We conclude by discussing how practitioners in 4D-CAD supported projects are inclined to follow mindfulness principles more than in manually coordinated projects.

A THEORETICAL PERSPECTIVE ON ENHANCING MINDFULNESS THROUGH 4D-CAD

This paragraph introduces the concept of mindfulness and elaborates its pragmatic value for studying how 4D-CAD impacts the reliability of coordination practices. The mindfulness concept we adopt stems from the domain of High Reliability Organizing (HRO) which studies how organizations operating large technical systems in high-hazard environments operate and cope with the errors and failures that they are exposed to. HRO-studies of failures, near-failures, and error-free operational processes provided concepts about how these organizations establish reliable operational performance. In this field, Weick, Sutcliffe et al. (1999) and Weick and Sutcliffe (2007) introduced mindfulness, a concept that
contributes to enhanced reliability. They argued that organizations that want to increase mindfulness need to effectively anticipate and contain unwanted events (see figure 1).

Anticipation focuses on how organizations can effectively identify, foresee and prepare for unwanted events. According to Weick, Sutcliffe et al. (2007), anticipation happens through three principles. According to the first principle, anticipating organizations are sensitive to operations. This means that they continually try to make sense of complexities in operational activities, aiming to understand how operations develop and might cause unwanted future situations. Second, anticipation occurs through reluctance to simplifications. This means that practitioners try to resist making simplified interpretations of reality, and consider no single situation as standard or common. Instead, organizations try to understand as much detail as possible to create various comprehensive pictures of reality. Third, anticipation is established by being preoccupied with failures. This means that organizations try to learn from previous faults, and continually search for causes of potential future failures.

Containment further focuses on how organizations recover from occurring unexpected unwanted events quickly. Weick et al. (1999) and Weick and Sutcliffe (2007) describe two principles that organizations follow to effectively contain. First, organizations commit to resilience as they buffer resources, include slack in schedules, and create cognitive variety (e.g. diversity of knowledge, excessive knowledge capacity). This allows organizations to quickly create, evaluate, and mobilize problem recovery strategies. Second, organizations defer to expertise. This means that professionals play a significant role when making decisions about recovery from unexpected events. Figure 1 schematically visualizes how the principles – categorized by the labels anticipation and containment - increase mindfulness, eventually enhancing reliable performance.

Although to a lesser degree than original high-hazard organizations, we assume that urban infrastructure reconstruction projects also face potential conflicts, errors and mistakes. These projects often involve many clients and contractors that manage distinctive project parts, have different design and scheduling practices, and work within fragmented supply
chains and tightly coupled project environments. In such complicated settings, project teams need to cope with potential problems effectively to avoid that obstructions force managers to undertake costly re-planning and improvisation actions. Given these points, we argue that urban infrastructure reconstruction projects would benefit from striving to enhance their mindfulness.

One way to enhance mindfulness is by implementing 4D tools. In essence, 4D integrates geometrical 3D-CAD models and time as fourth dimension (Koo and Fischer 2000) and herewith providing a visual integration of spatial and temporal elements of a construction project. Existing literature reports various applications of 4D tools. The tools have been applied for, for example, project communication, design review, and bid preparation (Hartmann, Gao et al. 2008), evaluation of construction methods and scheduling strategies (Russell, Staub-French et al. 2009), constructability reviews (Hartmann and Fisher 2007), construction planning, workflow planning and resource utilization (Wang, Zhang et al. 2004; Jongeling and Olofsson 2007), risk management (Kang, Kim et al. 2013), and safety management (Zhou, Ding et al. 2013). These various applications support project coordination tasks that eventually aim to enhance a project’s overall reliability. To the best of our knowledge, however, existing research has not yet focused on how 4D tools influence reliability of actual project coordination practices.

In terms of mindfulness, 4D-CAD features deliver visualizations of scheduled construction processes, and provide an outlook on future construction tasks, therewith increasing manager’s sensitivity to operations. Additionally, 4D tools can integrate multiple geometrical project models and schedules in visualization. The resulting insights in the planned sequence and process of the construction activities provide a comprehensive picture of the construction project. This eventually improves managers’ reluctance to simplifications. These integrated visualizations further help to identify interfaces and interdependencies between construction activities. By using clash-detection features, 4D would allow managers to detect possible conflicts, errors and hold ups, ultimately enhancing preoccupation with failures. Additionally, 4D can be used as a tool for planning and coordination discussions in multi-stakeholder meetings. Here, 4D can be used to develop and evaluate alternative construction schedules on-the-fly. The additional understanding resulting from such alternative scenarios eventually enhances managers’ commitment to resilience. Finally, 4D tools can improve a project’s performance along the deference to expertise principle, since they requires modelers to obtain task and sequencing knowledge from site managers, and work planners. Especially when modelling containment strategies in 4D, experts are empowered to provide important input (e.g. sequencing and constructability knowledge or productivity estimates) for the 4D-CAD model.

Previous section elaborates the hypothetical relation between 4D visualizations and enhanced mindful coordination practice. As existing studies do not report on 4D tools from the perspective of mindfulness, next sections empirically show that the concept can enhance our understanding of 4D implementation. To this end, we studied three cases and made a structured comparison of mindfulness in manual and 4D supported coordination practices.

**CASE DESCRIPTION AND METHOD**

We investigated mindfulness in coordination on three urban infrastructure reconstruction projects as follows. First, we purposefully selected urban reconstruction projects that involved various stakeholders. These stakeholders were, for example, local authorities, utility companies, and contractors. On each project, stakeholders were responsible
for making an integrated design and schedule for the reconstruction of sewerage tubes, pipes, cables, and street level infrastructure on intersections and main roads. On average the project durations were about six months. Based on these project selection criteria, we reasonably assume that our projects represent infrastructure projects that commonly take place in every Dutch municipality.

This study selected thee projects that could be distinguished based on their different coordination approaches. While the first project was coordinated manually, the other two projects included 4D tools. In the first project, we observed approximately five coordination meetings where coordination discussions took place ‘manually’ (i.e. they were based on paper-based drawings, sketches and a draft project phasing). Next, we observed four meetings on our second and third project. In these projects we introduced Autodesk Navisworks, an off-the-shelf 4D tool, to support manual coordination tasks. We helped practitioners creating 4D project models, and moderated the 4D tool during the multi-stakeholder coordination meetings.

During fieldwork we used a voice-recorder to record discussions and dialogues in stakeholder meetings. Practitioner’s informal discussions about coordination practices were also tracked in hard with field notes. We further kept track of our 4D modeling efforts and observations by using a research diary. Data was assembled, stored and analyzed in the qualitative data analysis tool ATLAS.ti. During data analysis, we first used ATLAS.ti to mark observed characteristics of manual coordination in our first case. For the two 4D cases, we similarly marked excerpts that described observed features and benefits of 4D. From these excerpts, we then developed a series of grounded codes that described different manual coordination characteristics, 4D benefits and 4D features. In a subsequent step we analyzed grounded each code and allocated it to its corresponding mindfulness principle. This culminated into an overview that, for both manual and 4D based planning, categorized and contrasted our grounded codes along the five mindfulness principles.

To illustrate how the data was coded and interpreted, we show how we categorized two excerpts from the 4D cases: In data from the second project, for example, a project team member requested the 4D model and argued: “if I can watch the process animation before a next meeting I can see whether … I can find obstacles and inform you about them”. We marked this excerpt and - together with similar excerpts - assigned it to a new code we named ‘identifying possible obstacles’. This specific grounded code generally described that 4D created awareness of possible errors and faults in early project stages. In the next step, we therefore assigned this specific grounded code to the theoretical mindfulness principle of ‘preoccupation with failure.’ In another example, a work planner explained how the 4D model could be used to evaluate the impact of delay. He argued that 4D could help to quickly compare the as-built situation with the as-planned schedule: “you can say, we have to be finished that week, but we are three days behind schedule. Do we still make it to finish this section timely? Our model nicely shows us that [the section] is indeed finished in time”. We assigned this excerpt to the code ‘delay recovery scenario’ since it describes how 4D supports on-the-fly delay assessment and creation of delay mitigation alternatives. This grounded code resembled the characteristics of ‘commitment to resilience’ and was later added to its corresponding mindfulness principle.
OBSERVED INSTANCES OF ENHANCED MINDFULNESS

This section provides an overview of our observations of mindful behavior in inner city infrastructure coordination. We use the five mindfulness principles for anticipation and containment and compared the paper-based manual project coordination (project 1) with 4D-CAD supported coordination (project 2 and 3). For each principle described in the first column, Table 1 describes general observations related to mindfulness in existing manual coordination practice (column 2) and instances of enhanced mindfulness in a 4D-CAD supported practice (column 3).

Table 1. Comparison of mindful practices on projects using manual coordination and projects supported with 4D-CAD

<table>
<thead>
<tr>
<th>Sensitivity to operations</th>
<th>Observed mindful behavior in manually coordinated project</th>
<th>Observed mindful behavior in 4D supported project coordination</th>
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<tbody>
<tr>
<td>Pre-occupation with failures</td>
<td>Strategies for dealing with potential construction problems were not created. Despite early identification of potential holdups, practitioners postponed problem solving tasks (e.g. site layout conflicts) to construction stage.</td>
<td>Development of 4D visualization enabled a work planner to identify inaccuracies and missing drawings. A visualization was shared with an external stakeholder to identify spatial and temporal conflicts. The development of a 4D visualization required work planners to model task-dependencies in scheduling software. This prevented them from making sequencing errors during schedule updating.</td>
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Reluctance to simplify

Formal project plans and phasing drawings contained little detail. Practitioners claimed that they acquired a more detailed overview of ongoing street and sewerage construction activities. When creating 4D-CAD models, work planners were triggered to schedule activities in greater detail. Resulting short term schedules triggered discussions about work sequencing (e.g. of sewer-line construction).

Commitment to resilience

Too optimistic estimation of the project’s cycle time did not include buffers for solving unwanted problems, increasing chances on delays and overruns. Project stakeholders argued that they could use 4D visualizations to evaluate delay mitigation strategies. It, for example, helped to evaluate whether a critical road intersection could still be paved in time, once a delay due to heavy rainfall and poor soil conditions occurred.

Deference to expertise

Managers found it hard to explain the formal project coordination structure. However, managers knew to contact right expert to informally (sometimes unofficially) solve problems. Deference to expertise due to 4D was not observed.

The comparison of mindfulness in the two distinctive coordination practices indicates that 4D supported projects tend to have enhanced mindful behavior compared to manually coordinated projects. One reason for this might be that existing manual coordination practices are loosely structured, while project information is fragmented or ill-structured. This provides no direct incentives to formally integrate schedules, and conduct thorough problem analyses, and consequently reduces a project team’s overall anticipation and containment capabilities. Instead, tools such as 4D-CAD sensitize managers more towards important operational details by forcing stakeholders to develop formal and detailed project plans.

In terms of mindfulness, 4D tools seem to enhance work planners and project managers’ sensitivity to operations as its visualizations increased understanding of simultaneously executed, interdependent construction activities. As argued by practitioners, this could help aligning construction plans with project stakeholders more easily. Projects that used 4D also demonstrate enhanced preoccupation with failure as the visualizations allowed the project team to identify and communicate potential construction issues. This is an improvement compared to the cumbersome – and often overlooked or neglected- conflict identification task in manual coordination. Finally, the development of 4D visualizations stimulated practitioners to follow the reluctance to simplification principle as they needed to deliver detailed formal construction schedules to make meaningful 4D-CAD visualizations. These required detailed plans are often not created in manual practices, but seem to provide important insights in project details.

In relation to the concept of containment we found that, 4D can increase the managers’ understanding of delay impacts by allows them to evaluate alternative mitigation strategies.
Finally we expected to observe *deference to expertise* behavior during this study. We assumed to observe this principle in problem solving situations where expert opinions had to be consulted to model containment strategies. This, however, did not take place during our presence in the field.

**DISCUSSION**

Our study of mindfulness on the different coordination practices also resulted in two suggestions for future research. First, our exploration of mindfulness in coordination should be extended with a detailed examination of how anticipation and containment can be observed in 4D projects. We argue for such operationalization of the mindfulness principles since it appeared that some principles (e.g. deference to expertise) are more difficult to observe in coordination meetings than others. To further investigate principles of containment, one could, for example, research in greater detail whether and how the deference to expertise principle could be observed in 4D projects. As we described earlier, we did not observe how 4D contributed to this principles in our study. One reason for this might be that, deference to expertise often occurs during ad-hoc problem solving, outside planned stakeholder meetings. As we only attended during official coordination meetings, we could hence limitedly observe this behavior. To better explore how 4D could support performance along deference to expertise, future research should spend significant time in the field with jobsite managers and work planners.

Another suggestion for future research is to evaluate the influence of researchers’ presence on mindfulness in the 4D projects. This would be worth investigating since this study’s 4D-CAD projects were all supported by the authors. Since we engaged with practitioners to model and actually use 4D tools it would be interesting from a mindfulness perspective to studying projects that implement 4D without any support of a researcher.

**CONCLUSION**

This study introduced a novel perspective for studying the organizational impact of 4D-CAD. We borrow the principles of mindfulness (Weick, Sutcliffe et al. 1999; Weick and Sutcliffe 2007) and introduce it to field urban infrastructure reconstruction projects. This was done by comparing both manual and 4D supported coordination practices on three urban infrastructure reconstruction projects. According to the mindfulness concept, organizations become more mindful when they develop capabilities to effectively follow principles to anticipate and contain unforeseen situations. We used these principles to make a structured comparison between manual and 4D supported coordination practices. To this end, we observed coordination meetings and additionally developed and implemented 4D visualizations for two projects. Our provisional findings show how practitioners on the 4D projects tend to follow mindfulness principles and, hence, can more effectively deal with potential problems. All in all, this helps to reduce rework, nuisance, extra costs, and delays.

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