USING 3D AND 4D MODELS TO IMPROVE JOBSITE COMMUNICATION – VIRTUAL HUDDLES CASE STUDY

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ABSTRACT: This paper explores the unique challenges and opportunities of communicating design and construction information at the jobsite and describes the format and content of an information delivery method that we call Virtual Huddles (VDC-aided morning jobsite meetings).

The research method used is direct participation in a test case (the construction of the concrete structure for a multi-family housing project) using VDC methods on a daily basis for approximately 4 months to support more than 40 daily morning meetings with the contractor's field workers and staff.

From the case observations and a structured interview, we observed that huddles are more effective when the content focuses on specific work instead of generic training or safety talks. However, it is not effective to deliver a high level of detail since workers will quickly forget it and come back later for specific dimensions. We also found that, on a daily basis, 3D models work better than 4D models. Some of the most important impacts of the huddles are a change in the structure of information distribution that empowers the laborers, a higher engagement of the laborers with the project, and an improvement in the communication between the contractor's site management staff and the laborers.

KEYWORDS: VDC (virtual design and construction), jobsite, contractor, communication, case study.

1 INTRODUCTION

Virtual Design and Construction (VDC) methods (such as 3D and 4D modeling) are being used to improve the production, analysis, and management of design and construction information in many phases and areas of construction projects (McKinney and Fischer, 1998; Chau et al., 2004). In this context, design information is the information related to the constructed products (i.e., materials, dimensions, locations, material finishing, etc.), and construction information is the information related to the construction processes to build the products (i.e., construction sequence, equipment, tools, work method, etc.).

The communication of this information to the ultimate doers (i.e., laborers) on the jobsite is, however, mainly based on 2D drawings and informal verbal explanations. Moreover, the verbal communication usually occurs only from the superintendent to the foremen and from the foremen to their laborers, limiting the direct communication between the superintendent and the laborers. This hierarchical communication seems to be due to practical reasons mainly: it is difficult to effectively communicate directly from the superintendent to the laborers in a construction environment. Low communications skills make this direct communication even harder. Makulsawatudom et al. (2004) identify low skills as one important cause of low productivity.

This type of communication (2D drawings and informal verbal explanations) plays an important role in some of the causes of low productivity identified in the literature (Rojas and Aramvareekul, 2003; Oglesby et al., 1989), such as experience, activity training, and motivation. This can be seen in the rework due to misunderstanding of design and/or construction information, the low engagement and motivation of laborers, and the non-productive time used on looking for tools and materials that should have been at the workface.

We wanted to study whether the use of VDC methods on the jobsite could reduce the communication problems by supporting the delivery of accurate, precise, and useful work instructions. Therefore, we tested the use of VDC methods to support the jobsite communication of design and construction information to the laborers. Using VDC methods on-site presents opportunities and challenges different from those in other phases of the project. We explored those opportunities and challenges by testing a VDC-aided method (Virtual Huddles) to deliver design and construction information on the jobsite.

The rest of this paper introduces the test case (section 2), explains the specific opportunities and challenges of using VDC on the jobsite (section 3), describes the Virtual Huddles (section 4), describes the impacts we identified after running Virtual Huddles during 4 months (section 5), and explains the conclusions we derived from our observations (section 6).

2 TEST CASE

The context of the test case is the multifamily housing industry, from the perspective of a cast-in-place concrete contractor, using direct hire labor.

The particular project consists of the concrete structure for three apartment buildings. This structure includes post-tensioned strip footings, conventional slabs on grade, walls and columns at the ground level, and post-tensioned deck for the first level. The rest of the building's structure is constructed with wood frames but it is not included in the test case as it was done by another contractor.

Figure 1 shows the form view of a POP (Product-Organization-Process) matrix of the test case at the contractor level. This is a simple way to describe the most relevant components of the product, organization, and process for the project (García et al., 2003).

POP Model

	Product	Organization	Process
Form			
	▼ Building A	▼ Contractor	▼ Build footings
	▼ Foundations	▪ Project Manager	▪ Lay out footings
	▪ Post-tensioned strip footings	▪ Superintendent	▪ Dig footings
	▪ Conventional strip footings	▪ Concrete foreman	▪ Reinforce footings
	▪ Walls	▪ Rebar subcontractor	▪ Pour footings
	▪ Columns	▪ Ready-mix concrete supplier	▪ Stress footings
	▪ Conventional slab on grade	▪ Steel and PT cable supplier	▼ Build walls
	▪ Post-tensioned elevated deck	▪ Equipment rent companies	▪ Lay out walls
	▼ Building B	▪ Smaller suppliers	▪ Reinforce walls
	▼ Foundations		▪ Set wall forms
	▪ Post-tensioned strip footings		▪ Pour walls
	▪ Conventional strip footings		▪ Wreck walls
	▪ Walls		▼ Build columns
	▪ Columns		▪ Lay out columns
	▪ Conventional slab on grade		▪ Reinforce columns
	▪ Post-tensioned elevated deck		▪ Set column forms
	▼ Building C		▪ Pour columns
	▼ Foundations		▪ Wreck columns
	▪ Post-tensioned strip footings		▼ Build slab on grade
	▪ Conventional strip footings		▪ Lay out slab on grade
	▪ Walls		▪ Set edge forms
	▪ Columns		▪ Grade
	▪ Conventional slab on grade		▪ Reinforce slab on grade
	▪ Post-tensioned elevated slab		▪ Set floats
			▪ Pour slab on grade
			▪ Wreck slab on grade
			▼ Build elevated slab
			▪ Set deck panels
			▪ Lay out elevated slab
			▪ Set edge forms
			▪ Reinforce elevated slab
			▪ Set floats
			▪ Pour elevated slab
			▪ Wreck elevated slab
			▪ Stress elevated slab

Figure 1. Partial POP matrix of the test case. The complete matrix includes function and behavior rows but these are not needed for this test case. The building activities (in the process column) have a direct correlation with the building components (in the product column). The actors (in the organization column) are also consistent with the elements in the other two columns since they participate in the processes to build the products.

Regarding the VDC methods used in the test case, we created a 3D model for the entire project that includes the concrete elements (without rebar, formwork, embeds, etc.). The organization and level of detail of this model was tailored to support its manipulation and use for daily work packages (Figure 2 provides an overview of the three buildings with a 3D model). We also created several 4D models to analyze different construction sequences. The IT infrastructure relevant for our work consisted of wireless internet access, a SMART Board, a projector, and laptops for the site management staff.

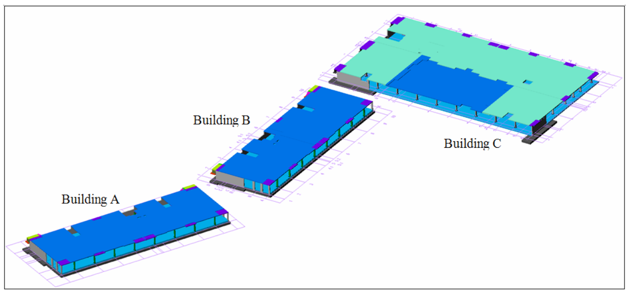

Figure 2. 3D model of the case study project. Buildings A and B are a mirror image of each other. Building C is larger but it still has the same basic building components (as the "product" column in Figure 1 shows).

3 OPPORTUNITIES AND CHALLENGES OF VDC USE ON THE JOBSITE

In this case study, we identified several unique opportunities and challenges in the use of VDC methods on the jobsite that differ from the use of VDC methods in other project phases.

3.1 *Opportunities*

- *Proximity to the work:* having the work face a few feet away from the virtual models presents several opportunities. It makes it easier to compare the 3D/4D models with the real objects and processes they represent. The proximity also significantly reduces the latency between asking a question in the field and the answer to the question based on an analysis of the models. The field people greatly appreciated the quick answers to their questions.
- *Admiration and enthusiasm for the new visualization technologies:* the scarce contact that workers have had with VDC methods makes them willing to interact (at least passively, see computer illiteracy in the next subsection) with 3D/4D models. In some occasions where the huddles were run without a model, the workers asked about the models and playfully required to have them the next time.
- *Information starvation:* the need for information is huge during the construction phase. Thus, the possibility of deriving information that was not originally available in simple 2D drawings, schedules, or other information sources, makes VDC methods very attractive to field personnel.

3.2 *Challenges*

- *Computer illiteracy:* laborers, foremen and even superintendents have little knowledge about computer systems. This made an active use (manipulation and revision) of 3D/4D models by the field people more difficult. In the case study, laborers and foremen interacted with the models only by looking at them. On a few occasions, foremen approached the SMART Board and pointed to things or drew something on the board. Their computer illiteracy had two main consequences: reluctance to have a bigger interaction due to fear of breaking something, and difficulty understanding information conveyed in the models.

- *Very dynamic conditions:* it is not news that conditions on jobsites are very dynamic. Even though this dynamic nature also occurs during the design phase, people experience it differently during construction since labor is usually not responsible for those changes but affected by them. This is a big challenge for the modeler since it is key to keep the 3D/4D models updated all the time. Otherwise the models lose credibility and usefulness. The biggest problem here was not the task to update the models since the project is relatively simple but the latency in getting answers through the formal RFI (Request For Information) process since the VDC methods were used only by the concrete contractor and nobody else on the project.
- *Language barriers:* this is an important issue in several countries around the world since a significant percentage of construction workers are immigrants (e.g., Mexican workers in the U.S.), who often do not speak the local language. This, of course, is a big challenge for understanding the design and construction information and contributes to the need for middlemen (see next point) in the communication as some laborers will need "translators". 3D/4D models make the communication more visual. Several laborers mentioned during the interview (see section 5) that sometimes they could not understand some of the superintendent's words during the huddle but the 3D model helped them to complement what they did understand.
- *Communication middlemen:* there are several middlemen between where the design and construction information is generated (i.e., architects, engineers, and construction managers) and the last users of this information (i.e., laborers). These middlemen are usually created by organizational structures (e.g., superintendent, foreman) but also by technical barriers (e.g., skill barriers create masters, language barriers create translators).

4 VIRTUAL HUDDLES

Considering the limitations of the traditional communication of design and construction information, we tested an information delivery method that we call Virtual Huddles to address the main challenges and take advantage of the opportunities of using VDC methods on the jobsite.

A Virtual Huddle is a VDC-aided meeting that supports the daily job-site communication. The purpose of this meeting is to explain to the laborers the work to be done during the day and to address the corresponding logistics and safety issues. Therefore, the meeting is done before the work starts every morning. The meeting must be attended not only by the foreman and superintendent but by all the workers (including laborers). This eliminates middlemen in the communication between superintendent and laborers (e.g., foremen). The use of 3D/4D models also reduces the need for translators.

The standard agenda of a virtual huddle starts with the review of the weather for the current day and the next days. After that the superintendent explains the activities to be done that day using 3D/4D models to support the explanations. This is an interactive process so the laborers ask questions and provide information while the superintendent explains.

4.1 *Preparing the huddle*

The preparation of the huddle starts with the daily schedule. Each evening the superintendent plans the work to be done the next day based on a weekly plan, the current situation of the project, and other factors such as weather, the general contractor's instructions, and resource and equipment availability.

After preparing the schedule, the superintendent or the project manager edits the 3D/4D models to support the explanation of the activities in the daily schedule. For 3D models, the superintendent/project manager should:

- Identify the 3D elements that are related with the activities of the next day's schedule.
- Turn off layers of elements that have not been built yet.
- Color code the elements as follows:
  - Red: 3D elements where top priority work needs to be done.
  - Yellow: 3D elements where lower priority work needs to be done.
- Draw any additional element in the model that could be useful to explain the work to the laborers (e.g., dimension lines, text, arrows, circles).
- Select views that facilitate explanation of the work.
- Turn off layers that obscure the view of the work area.

Some of these tasks are done "on the fly" during the Virtual Huddle (e.g., turning certain layers off and on) but the superintendent has to think about it before the huddle so s/he does not waste time in the meeting.

When using 4D models, the superintendent/project manager should evaluate whether it is necessary to use a 4D model to support his/her explanations. When necessary, a new 4D model has to be created. However, we realized during this test case that, in most situations, 4D models were not needed. The superintendent and the modeler (lead author) found it easier to use the 3D model as a pseudo 4D model by turning 3D elements on and off as needed since this gave more flexibility to show the status of the project and to manipulate the model during the huddle. 4D models were usually used for overall schedule discussions. Moreover, usually a 4D animation (e.g., a video file such as an AVI) worked better to deliver an idea than using the actual 4D model which allows the interaction with the model.

4.2 *Running the huddle*

The huddle usually lasted between 15 and 30 minutes. The number of attendees was around 20 persons. The physical set-up of the meeting was in a construction trailer with a projector and a SMART Board. Figure 3 depicts the schematic layout of the meeting space.

It is relevant to note that in a few cases we ran huddles with no 3D/4D models and we only projected the activities to be performed that day and, in some cases, 2D drawings. This happened when the lead author could not be present in the project to manage the models.

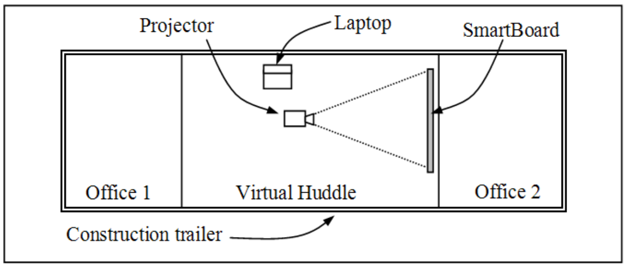

Figure 3. Layout of the meeting space. All the drawings were in the space where we ran the huddles so that we could use drawings to show information that was not in the 3D model (e.g., other contractors' work scope).

In general, 3D models were used in the huddle for three main purposes:

- Show specific locations in the project. This was very useful for two reasons: (1) language barriers sometimes made the understanding of specific terms difficult, and (2) many laborers do not read drawings and do not understand when the superintendent makes reference to certain areas of the project (e.g., specific column lines).
- Explain details of design information such as the way a wall and a column meet at a particular location or the complicated thickened areas of a post-tensioned slab.
- Explain a construction method. Usually, in these cases the superintendent needed to draw on top of the model to elaborate on the explanation.

4D models were used to explain the construction schedule to the laborers as a way to keep them engaged in the project.

5 IMPACT OF VIRTUAL HUDDLES

5.1 *Direct observation*

During the test case, we observed the behavior of the workers in the huddles and their attitude towards the VDC methods. We summarize our observations in the following points.

- *Distance to technology:* even though the workers were enthusiastic about the technology, they were always passive users and preferred to keep their distance.
- *Bypassing of middlemen:* several workers asked for information directly from the lead author (who was managing the 3D/4D models) bypassing the foreman and/or superintendent which would be the normal path. This was in part because of the easy access to the models through the modeler and part because the modeler spoke Spanish.
- *Appreciation of 3D models:* all workers liked the 3D models since they could easily get dimensions that were usually not in the drawings from them.
- *Indifference towards 4D models:* workers were more indifferent regarding the 4D models. They liked the animation of the schedule but they did not feel they were getting information that was very useful for them. As expected, management staff had a better evaluation of 4D models.

5.2 *Interview*

After more than 40 Virtual Huddles were run in the test project, we conducted a short interview of the staff and laborers in four groups: Project manager, Superintendent, Foremen and Laborers. The purpose of this interview was to measure the effectiveness of the huddles and the value of 3D/4D models for the huddles as perceived by the different actors of the project.

We asked the interviewees to answer the questions within a Likert scale of 5 points with 1 being the most negative appreciation, 3 a neutral one, and 5 the most positive one. The questions covered the following issues:

- Virtual Huddle's impact on the normal work
- Impact of 3D/4D model use on the Virtual Huddles
- Accuracy of the instructions (design and construction information) delivered in the huddle
- Precision of the instructions delivered in the huddle
- Usefulness of the instructions delivered in the huddle

Figure 4 summarizes the data captured in the test case for those five questions.

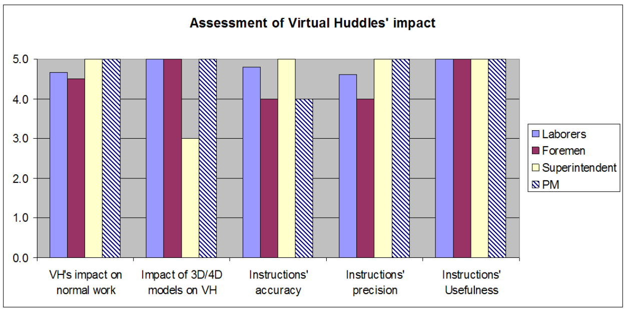

Figure 4. Assessment of the Virtual Huddles' impact. This graph shows a very positive perception of the virtual huddles and specifically the use of 3D and 4D models. The interviewees correspond to 100% of the subcontractor's people involved in the project (two crews of twelve and three laborers, two foremen, one superintendent, and one project manager).

As Figure 4 shows the general evaluation of the huddles was consistently positive for all the workers in the project. The graph also shows a neutral evaluation of the value of 3D/4D models for the huddles by the superintendent, which he confirmed with his comment: "3D models are good but you do not need to have them." However, the laborers evaluated the 3D/4D models as very beneficial for the huddles. This discrepancy is explained by the fact that the laborers benefit directly from the models by identifying locations and better understanding the superintendent's explanations while the superintendent benefits indirectly through the laborers' understanding which is not easy for him to evaluate on a daily basis.

The results also show a bias of the superintendent in the evaluation of the accuracy, precision, and usefulness of the instructions delivered in the huddles since he was the person that delivered the instructions. However, this bias does not contradict the general evaluation of the other actors who also have a positive evaluation.

6 CONCLUSIONS

- *VDC engineer onsite:* It is key to have someone on site that is able to create and revise 3D/4D models. The conditions on site are so dynamic that keeping a VDC engineer in the main office updated with what is happening on site would add a lot of extra work to the field management personnel. Moreover, by the time the VDC engineer would have updated the models the situation would likely be different again.
- *Stakeholders' involvement:* To fully take advantage of the opportunities of using VDC onsite, all the stakeholders (e.g., general contractor, architect, engineers, other contractors) of the project must be involved. The dynamic conditions of the project were particularly critical because the case study contractor was the only one using VDC methods on the project. Therefore, in many occasions we were waiting for answers from others who worked without 3D/4D models.
- *Change of information distribution:* The huddles provided an opportunity for the superintendent to talk directly to the laborers and vice versa. This type of communication is not very typical since, as we described before, usually the communication goes through the foremen who act as middlemen in the communication flow. This instance of direct communication empowered the laborers who felt they could have direct access to the superintendent.
- *Labor engagement and motivation:* The huddles proved to be a very useful engagement and motivation tool. Laborers were eager to know more about the project even about the scope and work of other disciplines. This motivation gain is aligned with the theory of motivation by job enrichment and hygiene factors (Herzberg, 1968; Khan, 1993)
- *Better superintendent-labor communication:* The change in the information distribution described above also contributed to improving the understanding of the instructions delivered by the superintendent and reduced the latency on finding out about issues such as lack of tools and materials and other information.
- *Multi-skilled labor:* Virtual Huddles present a great opportunity to implement a multi-skilled labor force since it allows for task-specific training. In our test case, plumbers and concrete crews collaborated on each others' tasks as both contractor companies belonged to the same owner. This opportunity was very valuable since, as Burleson et al. (1998) state, a single-skilled workforce strategy is "not necessarily responsive to construction sequence or the optimal use of worker skills."

This case study shows the value of the Virtual Huddles and some of their challenges. Currently, we are implementing Virtual Huddles in several other projects and exploring the challenges of escalating this effort company wide. Some of the next steps we have identified are:

- Standardization of the short-term planning on site based on a company-agreed generic WBS: the benefit of using a generic WBS is that it defines a common language for the planning across the different projects of a company. It also simplifies the planning effort for superintendents since they may select tasks from sets of predefined options and then customize them.
- Training of superintendents for the manipulation of 3D/4D models: this will increase the superintendents' appreciation of these methods (see Figure 4) and will allow them to run the huddles completely by themselves.
- Definition of incentives to use this information delivery method: as any new method it requires an initial effort and learning that has to be supported by appropriate incentives.

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