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A Work Instruction Template  
for Cast-In-Place Concrete  
Construction Laborers

By

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# **A WORK INSTRUCTION TEMPLATE FOR CAST-IN-PLACE CONCRETE CONSTRUCTION LABORERS**

Claudio Mourgues and Martin Fischer

## **Abstract**

The state-of-practice method to deliver work instructions to construction laborers (verbal communication plus construction drawing sets) often fails to effectively communicate the design and construction information that laborers need to perform their work. Poor quality of construction drawings (e.g., irrelevant, lengthy and unclear information) plus inadequate verbal communication skills of the actors in the field (field management and laborers) lead to many mistakes and inefficiencies. This problem is becoming critical today as these actors' cultural and social backgrounds are increasingly different and varied and construction projects are getting more complex. This problem prompts for a formalization of the information in the instructions that allows field management to deliver instructions more consistently and reduce the negative impacts of traditional verbal instructions.

This paper presents a template that defines the format and content for work instructions for cast-in-place (CIP) concrete laborers in the construction industry. We developed this template starting from characteristics of good instructions found in the literature and then tested and revised it through active participation in several multifamily housing projects for CIP concrete work.

The field-based validation showed that both laborers and field management personnel felt that instructions based on our template reduce the rework and the number of questions during the work and increases productivity and safety. Based on this validation, we claim that this template is a better way to communicate work instructions to laborers than the traditional practice. This template contributes to the

CIP concrete construction domain as it defines a foundation from where improvements can be made and enables leveraging of virtual design and construction methods that can interact with the formalized information in the instructions.

**Keywords:** Construction, work instructions, template, cast-in-place concrete, field information

## 1. Introduction

Today's methods and tools (e.g., cost estimating methods and tools, planning and scheduling methods, simulations, building information modeling (BIM)) help AEC professionals produce, analyze and manage design and construction information. However, there are still quality, safety and productivity problems at the jobsite when laborers use this information to build the project. Why is this? A reason is that the communication of project information to the final doers of the project (i.e., laborers) is ineffective.

Emmitt and Gorse (2003) state that to achieve effective communication, instructions must be clear, concise, complete, error-free, meaningful, relevant, accurate, and timely to those receiving them. Several of these characteristics do not occur when giving work instructions (mix of design and construction information) to construction laborers. The traditional method to deliver these instructions is via construction drawings and informal verbal communication. Previous studies and our experience show that this method negatively affects the field work as described below.

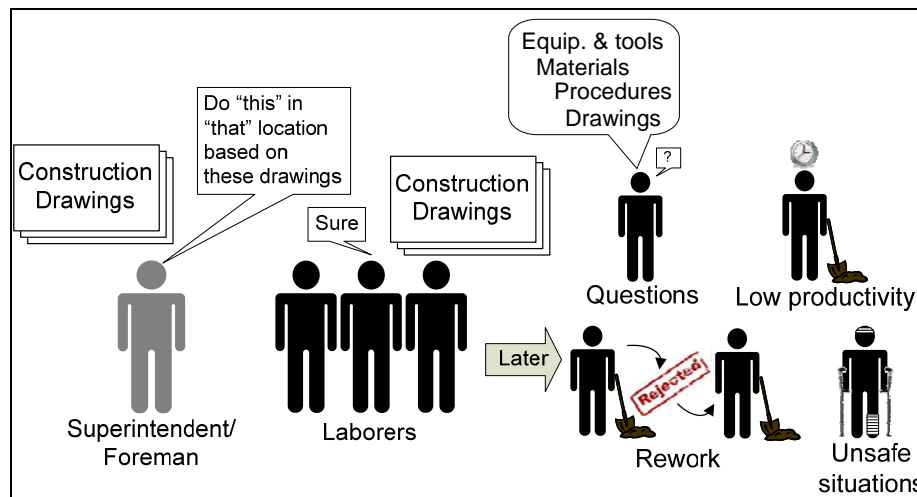
- **Productivity:** construction drawings are frequently incomplete, not coordinated between the different disciplines, difficult to read, and not updated. This poor quality of the drawings lowers labor productivity and increases the chance of having construction claims (Gao et al., 2006; Makulsawatudom and Emsley, 2003; Kagan, 1985). Also, the content of construction drawings usually addresses more

than one discipline. Therefore, some of the content may not be relevant for the work the laborers of a particular discipline are going to carry out. This makes it more complex for laborers to extract the information they need. It is important to note that BIM/4D-based clash detection is improving the coordination of drawings (Khanzode et al., 2007). However, this improvement has not adjusted the format and content of the drawings to make it easier for laborers to find the relevant information in each of the relevant drawings. On the other hand, poor communication skills also lower the productivity at the jobsite (Makulsawatudom et al., 2004) which is worsened by language barriers, low formal education levels, cultural differences, and the noisy environment.

- **Workface questions:** During a previous study on jobsite communication (Mourgues et al., 2007), we observed that traditional verbal instructions lead to many questions during the execution of the work such as: how do I set the forms in a column with that shape? How many panels do I need for that part of the wall? How far from my reference point is that column? These questions reduce labor productivity as they take time to be answered and affect the product quality when laborers make wrong assumptions instead of looking for an answer. From our observation/participation on three projects, we classified these questions in 4 groups:
  - o **Drawings:** related to drawing interpretation, clarity and completeness (e.g., dimensions, locations, details).
  - o **Instructions:** related to work procedures.
  - o **Equipment and tools:** related to equipment and tools needed to perform the work.
  - o **Material quantities:** related to what and how much material is needed for the work.
- **Rework:** Kaming et al. (1997) identified poor instructions as the second cause of rework in Indonesia. Also, the workface questions increase the rework as, sometimes, laborers make assumptions that lower the quality of the work.

- **Safety:** We have also observed in our previous research that the instruction misunderstanding produces unsafe situations as many safe procedures are not understood and followed. This also increases the need for safety inspections.

Summarizing, as Figure 1 shows, the use of traditional verbal work instructions plus construction drawing sets leads to many questions at the workface, rework, low productivity, and unsafe situations. Moreover, the informality of verbal instructions implies a high variability in both the delivery of instructions and the final performance of the laborers, and, as one of the Lean Construction principles states, the reduction of variability is key to improve performance (Thomas et al., 2002). Therefore, there is a practical need for a better and more formal means to communicate work instructions.



*Figure 1. Illustration of verbal communication of work instructions and its negative impacts on the field. At the left, the superintendent/foreman verbally explains to laborers what to do and where, using the construction drawing sets. At the right, the figure shows the consequences of this poor communication.*

At the same time, the use of virtual design and construction (VDC) methods and tools, such as BIM-based estimating and energy simulation (Staub-French et al., 2003; Bazjanac, 2005), are formalizing design and construction management information and tasks. So, there is an opportunity of linking these formalizations with the

information laborers need to improve the quality of work instructions. However, to take advantage of this opportunity, we need to formalize the content and format of the instructions.

However, literature on construction work instructions is scarce. Reviews of construction research topics such as Abudayyeh et al. (2004 and 2006) and Sriprasert and Dawood (2001) show no research on work instructions. Most of the literature on construction communication does not address the communication of instructions to laborers but focuses on communication at the design and management levels (Terry, 1996; Bakos, 1997; Cory, 2001; Gilleard and Gilleard, 2002) or discusses language barriers (Loosemore and Lee, 2002). Job-assignment sheets (Oglesby et al., 1989) are one of the few references to work instructions in construction but a formal study and analysis of their content and format is missing. Even outside the construction domain, several studies explain characteristics that make instructions good for different disciplines (LeFevre and Dixon, 1986; Heiser et al., 2003; Agrawala et al., 2003; Smith and Goodman, 1984), but these studies do not define the format and content of these instructions. Therefore, besides the above needs for better and more formal work instructions there is also a need for a scientific foundation for the content and format of good work instructions.

In a few words, today's method to prepare and communicate instructions for laborers does not make the needed design and construction information ready to be used by the laborers, as in Heidegger's concept of ready-to-hand (Koschmann et al., 1998). In this paper, we focus on the communication link (the actual preparation of the instructions and the related challenges are discussed in a different paper) between the people preparing this information and its users and address the needs explained above by formalizing a template to deliver written design and construction information to laborers (field instructions template). This template aims at reducing rework and the number of questions and increasing productivity and safety. This formalization also intends to reduce the variability of both the communication of design and construction

information and the laborers' performance. Since formalizing the information involved in the communication of work instructions for all types of construction work may or may not be possible, we focused on the CIP concrete domain for residential buildings as this domain is an important part of the industry and it is field-intensive. Within this domain, the applicability of the field instructions template depends on the type, complexity, and scope of activities.

Section 2 of this paper describes characteristics of good instructions found in the literature. Section 3 explains how we used these characteristics plus active participation on a project to develop and test the field instructions template. This section also describes the template in detail and its range of applicability. In Section 4, we validate the value of the field instructions template on two construction projects by qualitatively assessing its impact on the identified problems. Finally, Section 5 reports the main findings of this research.

## **2. Literature on work instructions**

The first section discussed the reasons why verbal work instructions are often poor instructions. Therefore, we need to determine the criteria that define good instructions. Researchers have used different criteria such as the instructions' level of use (Antifakos et al., 2002), their usability (LeFevre and Dixon, 1986; Heiser et al., 2003; Agrawala et al., 2003), their clarity (Heiser et al., 2003; Agrawala et al., 2003), and their readability (Smith and Goodman, 1984). We use the properties defined by Emmitt and Gorse (2003) (i.e., clear, concise, complete, error-free, meaningful, relevant, accurate, and timely) as our goodness criteria because they are the most comprehensive. These properties are directly related to many of the criteria previously used by other authors (see above). However, these properties are not specific enough to guide the definition of an instruction template. Thus, we use these properties as the



criteria to gather a set of specific characteristics of good instructions for construction from the literature. We then design the template with these criteria.

## **2.1. Work instructions in construction**

Oglesby et al. (1989) present one of the few studies that address the topic of work instructions in construction. The authors describe the use of job-assignment sheets as part of the preplanning of construction work, although, as they recognize, this is not a popular practice. Job-assignment sheets are written instructions that intend to answer all laborers' questions before they are asked. So, laborers must be able to perform an activity with only the sheet that describes that activity. These sheets also serve as a record of the work that was done. Although the authors do not explicitly state their goodness criteria, job-assignment sheets are driven by completeness (i.e., answering all laborers' questions). However, these sheets are not self-contained since they refer to blueprints from where more information (e.g., dimensions, quantities) must be derived by the laborers (i.e., they are not concise and complete). Furthermore, the description of the steps to be followed by the laborers is unstructured and distributed in several sections of the sheet (e.g., job, sketches, and method to be used) that could be different for new instructions as the authors do not present an explicit format and content for these sheets. This lack of a formal format and content makes the job-assignment sheets unclear for the laborers each time new sheets are produced.

In practice, the implementation of job-assignment sheets, when used, has become another management requirement where subcontractors submit a description of how a certain task will be done. This description is reviewed and approved by the general contractor before the task is done to ensure safety and coordinate with other crews (this description is usually called work method statement). However, this description is not used to communicate to the laborers what they have to do and how they have to do it since the description is too general. This communication is still done in the traditional way (i.e., informal verbal communication and construction drawing sets).

In spite of the identified shortcomings, the concept behind job-assignment sheets is a good starting point for our research since it is the only formal reference to work instructions in construction. This concept implies that good instructions are written instructions that intend to answer laborers' questions, are the only information source for the work described in that instruction, and can be used to track the work that was done.

In some construction disciplines such as piping, some contractors produce written instructions for their workers as part of the work packaging process (Kim and Ibbs, 1995). However, those instructions suffer from the same shortcomings of job-assignment sheets as there is no formal and explicit definition of format and content for those instructions and they reference external information.

## **2.2. Characteristics of good work instructions**

Outside the construction domain, different authors have identified different characteristics of good instructions.

LeFevre and Dixon (1986), based on the instructions' usability, show that instructions with examples are better than generic instructions. In the context of construction, this means that instructions specific to a project, activity and location are more useful for laborers than generic descriptions of work procedures as they are more relevant (one of our goodness criteria) to the laborers' work.

Austin et al. (1995), in the field of medicine, show that illustrations improve the comprehension of instructions. This is particularly true in construction, where much of the information is of graphic nature which is more clearly described (another of our criteria) with images than with textual descriptions.

Smith and Goodman (1984) discuss how explanatory schemes that organize instruction steps based on the structure or the function of the elements to be built contribute to a faster reading and higher comprehension of instructions (these are related to the instructions' clarity). In construction, work instructions address a particular building element (e.g., wall, slab, column) or functional system (e.g., ventilation supply, sewage system), so it is not possible or meaningful to organize instruction steps by these criteria as they are common for the whole instruction. Instead, a useful explanatory scheme is organizing the steps by the operation or task acting on that structural element or functional system.

Antifakos et al. (2002) argue that most people do not use written instructions for many reasons (e.g., laziness, self-confidence, people's different levels of expertise, instructions' quality, instructions' linearity). They propose just-in-time instructions that are part of a proactive, unobtrusive and context-aware system. This system can identify the state of the environment (e.g., the application of oil spray during the setting of wall forms) and deliver the instructions as they are needed for that particular state. Thus, this system addresses the relevance and timing of the information. Such a system will impact the format and content of the instructions as each portion of instructions that is delivered for a particular state of the environment must be self-contained. However, Antifakos et al. do not mention the construction industry as an application area, and, actually, there are two main challenges for this application in construction: a messy environment that makes it difficult to identify its state and the difficulty to make a system unobtrusive for construction laborers as they need mobility and carry a lot of tools and equipment. In spite of this, technologies such as wearable computers (Miah et al., 1998; Fuller et al., 2003), augmented reality (Webster et al., 1996), RFID (Jaselskis and El-Misalami, 2003), and intelligent data analysis algorithms (Zou and Kim, 2007) present a potential opportunity to implement this type of instructions in the construction industry in the future. For the time being, good instructions must still be delivered complete ahead of the work instead of delivered in self-contained portions of instructions as they are needed by the users.

Heiser et al. (2003) and Agrawala et al. (2003) focus on assembly instructions for the end users of manufactured products. Heiser et al. describe principles to design these assembly instructions while Agrawala et al. formalize these principles and, based on them, automate the creation of instructions. The goodness criteria for these principles are the clarity and usability of the instructions. The authors used cognitive psychology techniques to investigate “people’s conceptions of object assembly and effective visualizations of the assembly” and, based on the results, they identified the design principles described below.

- **Hierarchy and grouping of parts:** the elements of the object to be assembled are perceived with a hierarchy of parts and people prefer, when possible, that a group of parts in the same hierarchical level (e.g., legs of a table) are added at the same time or in sequence one after another.
- **Hierarchy of operations:** people think of the assembly operations as a hierarchy of actions. At higher levels, these actions combine sub-assemblies and at lower levels the actions address parts of each one of those sub-assemblies. Usually, assembly instructions contain two-level hierarchies.
- **Step-by-step instructions:** people prefer instructions that show a sequence of diagrams instead of one diagram with all the information.
- **Structural and action diagrams:** action diagrams (i.e., diagrams that use guidelines to show where new parts will be attached with existing parts of an assembly) are better than structural diagrams (i.e., diagrams with all the new parts already attached to their final position in the assembly) to show assembly instructions.
- **Orientation:** most objects have orientations that maximize the visibility of all the relevant parts.
- **Visibility:** the new parts added in each step must be visible.

We recognize differences between assembly and construction work instructions that affect the characteristics that can be derived from these principles.

- **The user's knowledge/expertise:** the user of assembly instructions has less knowledge/expertise about the assembly process than the knowledge/expertise that the user of construction work instructions has about the construction process since the latter is a professional in the discipline. This makes it necessary to focus the content on the key elements of both the design and construction information – not including every single step – since, based on our experience, construction laborers quickly dismiss information they think they know and stop paying attention to the instructions.
- **Work environment:** the tasks described in work instructions are usually performed in a harsher environment than the tasks described in assembly instructions. This implies constraints on the format (e.g., media, length, organization, size, color coding, etc.) of the work instructions. In the same line, Gao et al. (2006) recommend the use of color drawings to improve project communication.
- **Process complexity:** Assembly instructions usually depict a simpler process than construction work instructions. This allows showing more detailed information in the assembly instructions.

Summarizing, we define the following characteristics of good construction work instructions from our literature review. Work instructions:

- are written instructions that answer laborers' questions;
- are complete so that laborers need only one work instruction to perform the work described in that instruction;
- are used to track the work that was done;
- are self-contained (i.e., do not refer to external documents);
- have a formal format and content for all potential instructions;
- are specific to a project, activity, and location;
- contain illustrations;
- organize instruction steps based on the tasks acting on a building element;

- are delivered completely before laborers need any particular part of the instruction;
- follow a step-by-step sequence of action diagrams (however, since these instructions are for professionals, the instructions do not need to include every single step but only the most relevant steps, and the diagrams must maximize the visibility of the elements added in each diagram);
- have a format that guarantees clarity in the harsh environment of construction (e.g., color drawings); and
- show only critical details and leave general trade knowledge out.

However, this set of characteristics is not specific to construction and it is not immediately useful for a contractor as it does not specify the format and content of good work instructions. Therefore, there is a clear need for a template that defines this format and content based on characteristics specific to construction. But before explaining how we developed our field instructions template from this initial set of characteristics, we need to explore the literature about describing the work scope of activities to allow producing work instructions that are specific to a project, activity and location, as stated by one of the characteristics above.

### **2.3. Describing an activity**

Activities are usually described arbitrarily (i.e., planners name an activity without following a standard) or using construction taxonomies such as UNIFORMAT II (ASTM, 1997) and MasterFormat (CSI, 2004) that do not formally describe the work scope of the activity. This makes it difficult to define the content and format of a potential instruction for that activity. In this paper, we refer to an activity as a construction process that happens in a specific work area (i.e., an activity is a specific instance of a construction process)

Darwiche et al. (1988) define the Object-Action-Resource activity ontology as the basis for their automated project planning system. Using this ontology, they describe

an activity as an object, or building element, (e.g., slab, column) that receives an action (e.g., weld, install, pour, paint) that uses resources (e.g., crew X, concrete, pump, crane). Note that their definition of resources includes labor, material, and equipment. In the context of work instructions, we do not need to include labor and equipment as they do not provide information about the work scope of the activity. Despite this difference, this ontology describes the main elements that are relevant for our case but it fails to describe the location of the activity.

On the other hand, Seppänen and Kenley (2005) state that the three levels of location breakdown structures (LBS) for typical building projects are buildings, floors, and spaces.

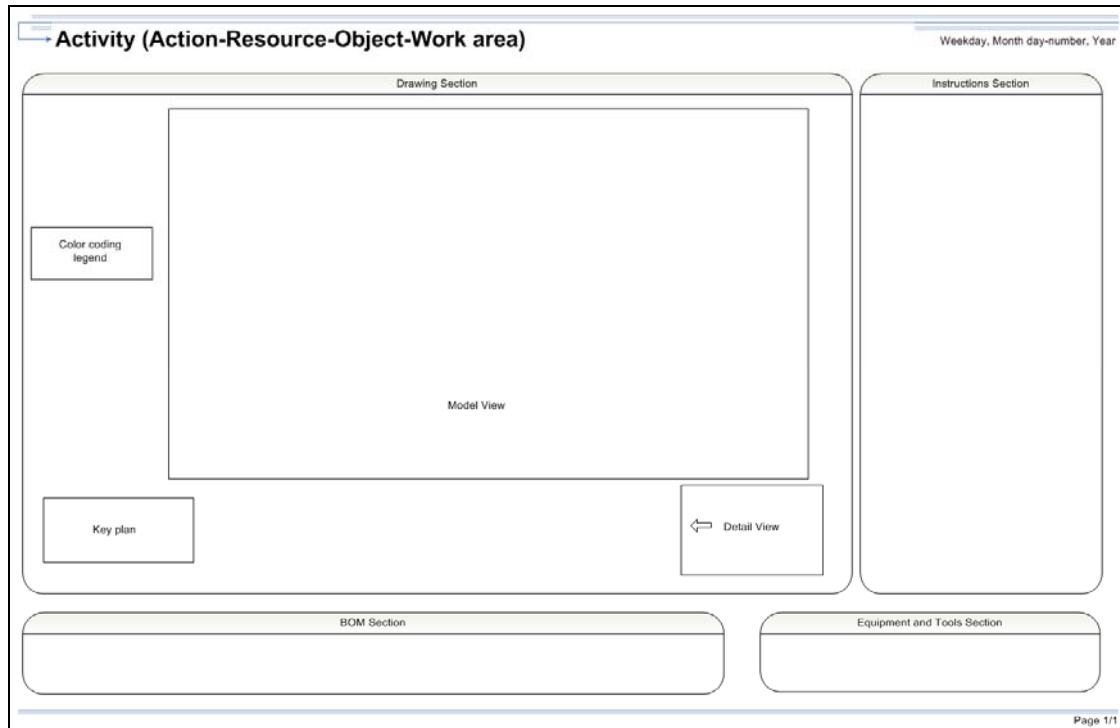
Putting together both descriptions, we can describe an activity as an Action (e.g., place, put, dig, paint) that happens on a Resource (e.g., rebar, form, cable, concrete) of an Object (e.g., wall, column, slab) in a particular Work area (AROW ontology). We define the work area using three elements (analogous to the three LBS levels): a building (e.g., building X, garage Y), a level (e.g., foundations, 1<sup>st</sup> floor), and a zone (e.g., zone between different column lines, mechanical room).

The next section explains our field instructions template and the research method we used to develop it, based on the characteristics of good instructions we described above.

### **3. Field instructions template for construction labor**

A field instruction is a work instruction that uses our template (Figure 2) to deliver design and construction information to construction laborers in a particular format and content. We introduce this new term to differentiate field instructions from regular work instructions that could follow any format (even verbal instructions) and to

emphasize that field instructions directly support the field work instead of being part of generic training or documentation programs and communications.



*Figure 2. Field instructions template. This template contains four sections (i.e., drawings, instructions, equipment and tools, and BOM sections) that group design and construction information that is specific to the project, activity, and location. The drawing section includes four information types: model view, detail view, key plan and color coding legend. The size of the template (11”x17”) is consistent with the size of the A3 reports used in Lean Manufacturing for problem solving (Sobek et al., 2008). Section 3.2 explains this template in detail.*

Before explaining the template itself, we explain the research method we followed to develop this template, connecting it with our literature review findings. After explaining the field instructions template, we discuss its range of applicability.



### **3.1. Research method**

Developing a template for work instructions requires a close observation of what works and what does not work in the field. That is why we decided to use a practical approach instead of a lab-based approach such as cognitive-psychology, used by Heiser et al. (2003). We used an active-participation approach where the main author worked as a project engineer for a cast-in-place (CIP) concrete contractor in a multifamily housing project. The research method followed three steps: development of an initial template based on our literature review findings and interaction with the foremen, field testing of that template, and refinement of the template based on laborers' feedback and our observations.

In the initial phase of the research we defined a template with the step-by-step approach suggested by the literature. We found it difficult to create action diagrams because the steps illustrated in the instructions were not assembly steps (e.g., connect, screw) but broader action steps (e.g., dig, place, paint, cut). Figure 3 illustrates two examples of these early instructions.

We realized very quickly that we had to change this approach. The foremen's feedback and our observations suggested that the instructions were unclear and too long (i.e., contrary to our goodness criteria). This realization led to a drastic change of the format of the field instructions from a step-by-step approach to an all-in-one approach. This new approach does not follow a step-by-step sequence of action diagrams but it uses one or a few images to show the relevant information irrespective of the particular instructions steps.

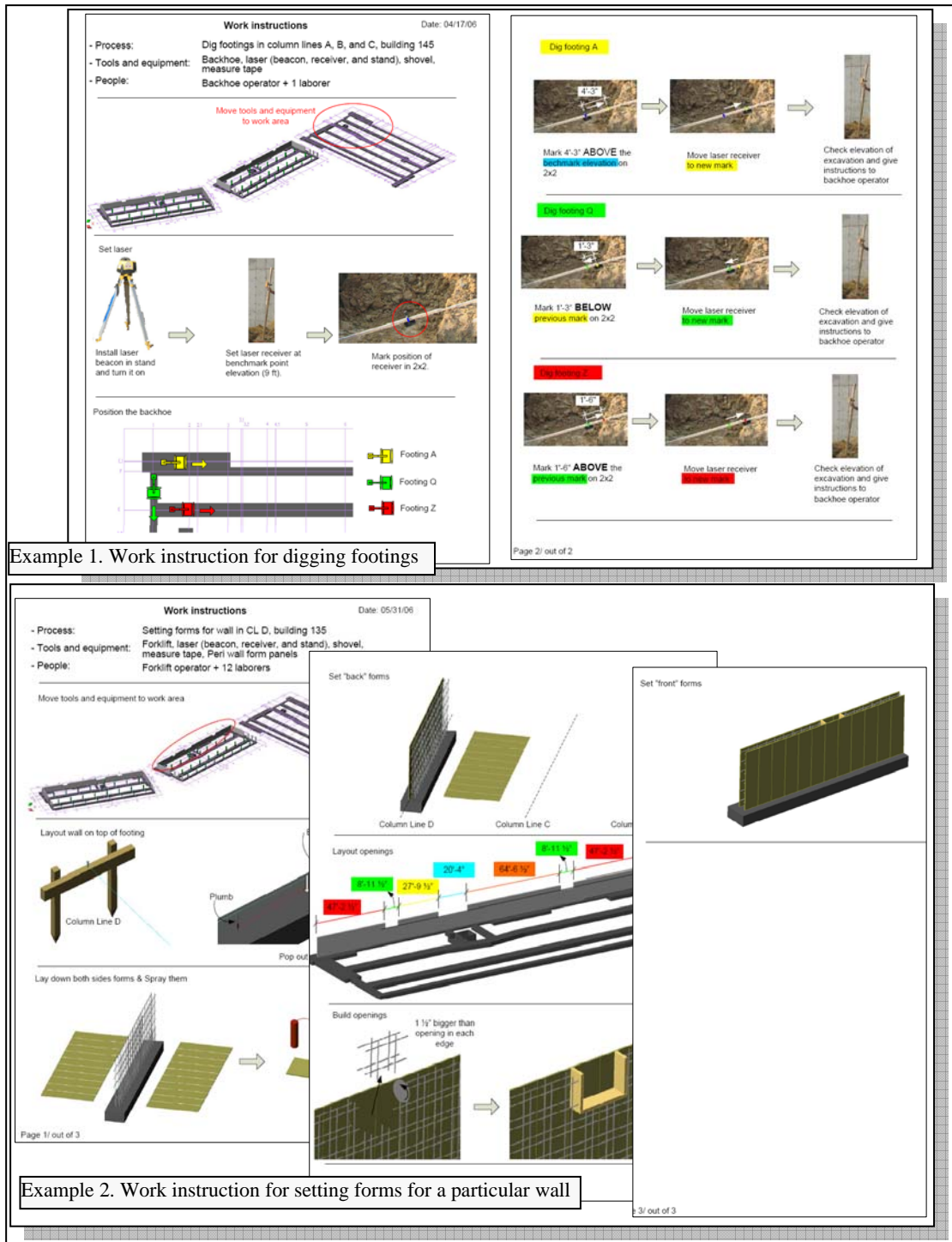


Figure 3. Examples of step-by-step instructions. Each step in the instructions is separated from the others with a horizontal line and illustrated with one or more diagram or picture. These instructions were assessed as unclear by the foremen and they were long, considering the small amount of information that they contain.

Figure 4 shows three examples of instructions with an all-in-one approach. The early instructions were mainly annotated and color-coded images from the project. At this point we started the second phase of the research: field testing of the instructions. We gave these instructions to the crews to support their daily work and collected their anecdotal feedback and our own field observations. We also attempted to obtain quantitative impact information but it proved to be unfeasible (see section 4). Based on this feedback and the characteristics we identified from the literature (with the exception of the step-by-step approach), we reviewed these instructions and incorporated and organized information based on the types of workplace questions.

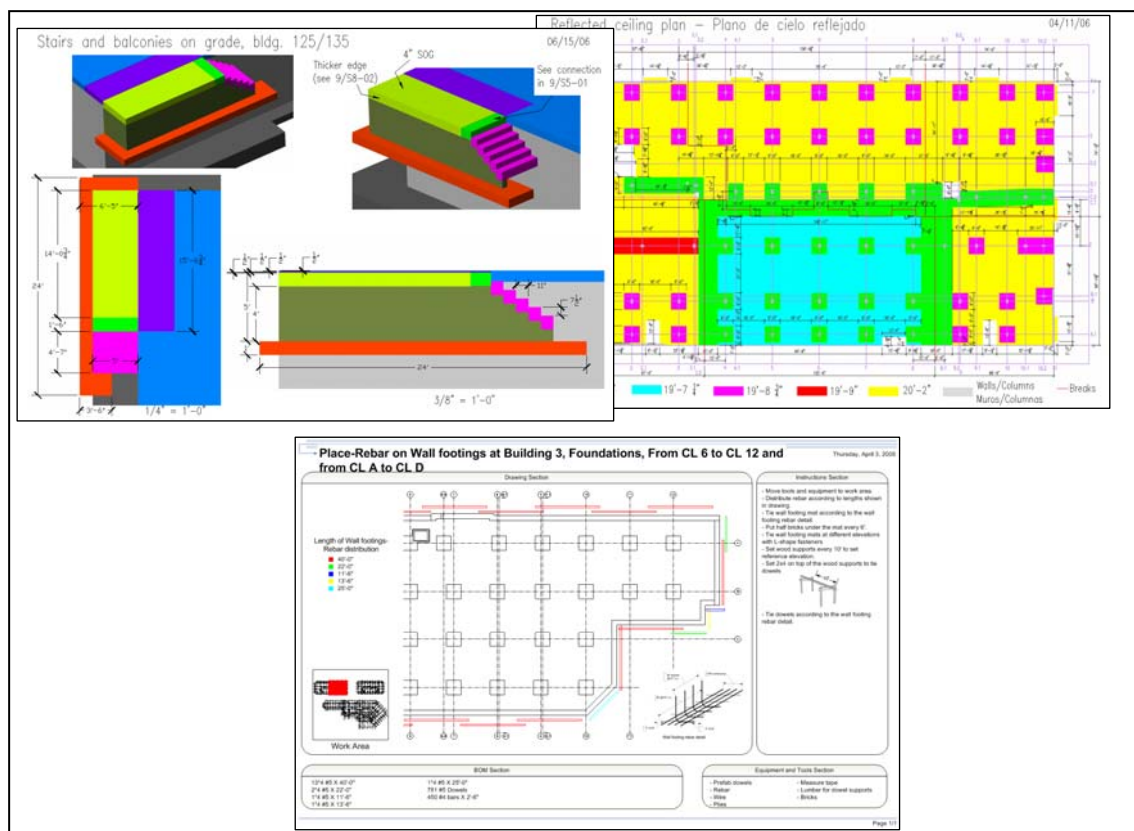


Figure 4. Examples of all-in-one instructions. These instructions contain images that illustrate the needed information as a whole instead of diagrams illustrating each individual step. The upper images show early instructions that were mainly annotated and color-coded drawings in different views with little extra information. The lower image shows a later field instruction that includes more information.

The next section explains in detail the format and content of the final field instructions template and its connections with the characteristics of good instructions.

### **3.2. Field instructions template**

Figure 5 shows an example of a field instruction (based on the template shown in Figure 2) for placing rebar on the wall footings in a particular work area. We will use this example to explain each part of the field instructions template.

It is important to note that the goodness criteria we used to define the field instructions template also require that the production of the field instructions is just-in-time (JIT) so that instructions include up-to-date information and avoid coordination challenges of the relevant information (e.g., architectural and structural drawings).

The first element of the template is the title, which defines the work scope as the activity for which the instruction is needed. The title also indexes the field instructions so the company can find a particular instruction that was used among the many they will produce for a project. The title uses the AROW ontology described in section 2.3. In our example, the title describes the activity: Place (action) the rebar (resource) of the wall footings (object) at building 3, foundations, from column lines 6 to 12 and A to D (work area).

The title element includes a couple of the characteristics of good instructions we found in the literature. It is specific to the project, activity and location since it refers to specific resources, objects and work areas of the project. It also has a formal format that minimizes misinterpretations and allows tracking the work done with the instructions by object, resource and work area.

# Place-Rebar-Wall footings-Bldg. 3, Foundations, From CL 6 to 12 and from CL A to D

Wednesday, April 9, 2008

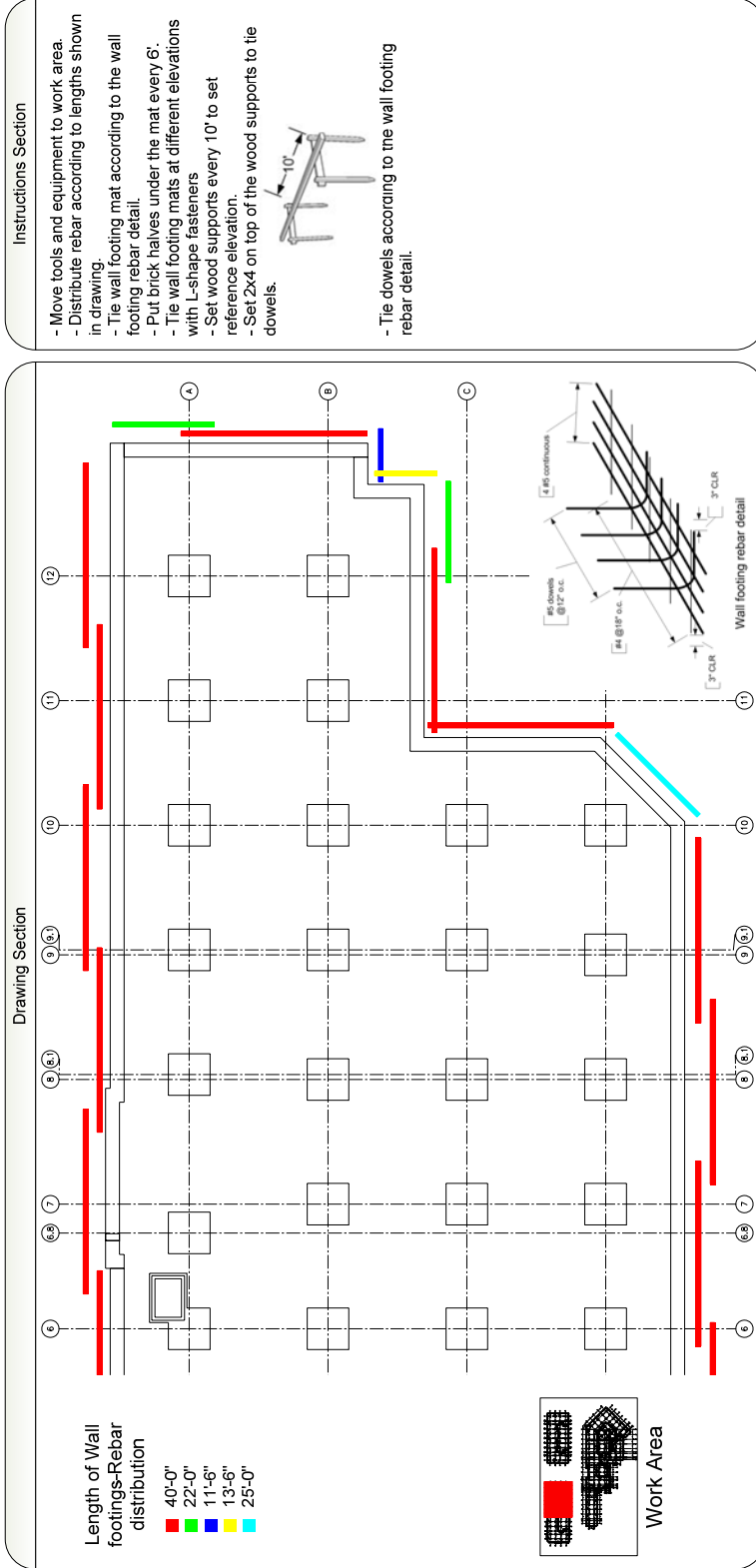


Figure 5. Field instructions example. The title of the instruction defines its scope (i.e., place rebar of wall footings at building 3, at the foundation level, from column lines 6 to 12 and A to D) using the Action-Resource-Object-Work area format.

The other main elements of the template are four sections (illustrated in Figures 2 and 5 and described in Table 1) that group the design and construction information. This information organization answers the typical questions (described in Section 1) laborers have at the workplace. The names of these sections relate to concepts that laborers easily recognize. For example, the drawing section could also be named “building design information” but that name would not be easily understood by the laborers.

Table 1. Sections of a field instruction. These sections address the types of questions laborers have at the workplace.

Section	Description
Drawings	This section contains design information (i.e., locations, dimensions, materials, etc.).
Instructions	The construction steps and special considerations that laborers must follow to perform the work described by the field instruction.
Equipment and Tools	The equipment and tools needed to perform the work described in the field instruction.
Bill of Materials (BOM)	The materials and their quantities needed for the work included in the field instruction.

### 3.2.1. Drawing section

This section addresses several characteristics of good instructions. It is self-contained (there are no references to additional drawings), it is where most of the illustrations are (there can be some in the instructions section), it uses color coding to maximize the clarity for the harsh environment of construction, it is independent of other drawings (laborers need only these drawings for their work), and it has a formal content – i.e., model view, color coding legend, detail view, and key plan – that organizes the information to make it easier for the laborers to find what they look for.

The content elements mentioned above come from our rationalization of our interaction with laborers and field management personnel. These four elements (i.e., model view, detail view, color coding legend, and key plan) help the laborers to quickly find the information they are looking for, since, as Figure 2 shows, they are consistently distributed in the drawing section. Figure 6 highlights those elements in the drawing section of the example in Figure 5.

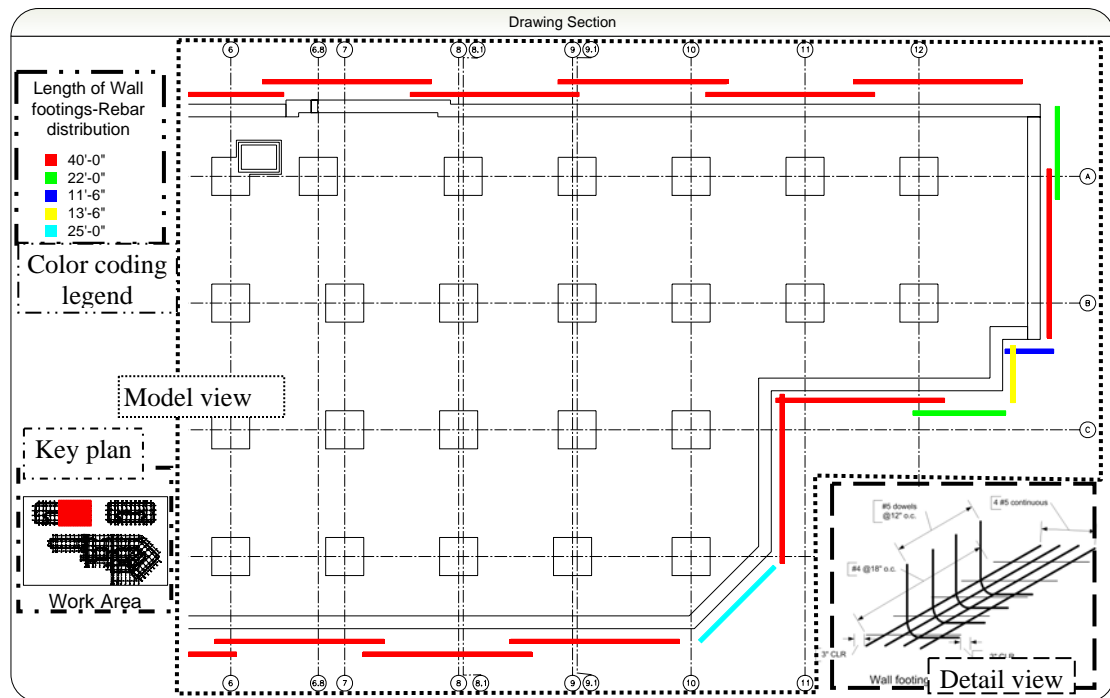


Figure 6. Elements of the drawings section: model view, detail view, color coding legend, and key plan.

- **Model view:** shows design information that is relevant (based on the company's best practices as explained below) for the activity described by the field instruction. The number of model views depends on the information required for that particular activity. In our testing and validation phases we always used only one model view per field instruction. These views can be plans, reflected views, elevations, sections or 3D views. They should be color coded to describe information more clearly and concisely (as suggested by Gao et al. (2006) and by

the laborers during our testing phase). The views can also be dimensioned and/or annotated if necessary to deliver as much information as possible but leaving irrelevant information out. For example, if the footing layout is already done (i.e., shape is painted on the ground), laborers do not need horizontal dimensions (they still need elevations) to excavate the footings. We call it model view because it is a view extracted from the project model (it could be a 3D model or 2D drawings).

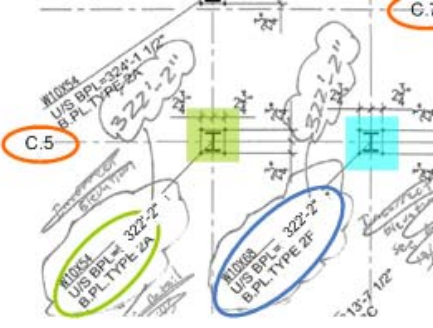
- **Detail view:** shows details (e.g., rebar configuration shown in Figure 6) that otherwise would be too hard to depict in model views. When different details apply to different areas in the model, they can be referenced by color coding or labeling.
- **Color coding legend:** explains the color coding used in a model view. One legend is enough for multiple model views if they share the same color coding.
- **Key plan:** identifies the location in the project where the activity described by the field instruction occurs.

The content and format of the model view (i.e., the elements included in the view, the type of view and the color coding of the included elements) depend on the construction process (activity type, i.e., the actual location of the activity is not relevant) described by the field instruction. For example, the design information needed for a certain construction process may be better described by floor plans than elevations (e.g., lay out footings). The same applies to the color coding scheme used in the model view and the building components (e.g., footings, columns, slab on grade) included in that view. However, the final decision on the type of view, the view's color coding, and the view's content that are better for a particular construction process is up to the companies (ideally a team of experts from the field and main office of the contractor) using field instructions to communicate instructions to their laborers because these are subjective choices. Table 2 presents examples of construction processes with the respective most useful model views based on a contractor that participated in the testing phase (see section 3.1).



Table 2. Examples of construction processes and their respective model views for the drawing section of the field instruction. In some cases, we include more than one construction process in the same field instruction (e.g., lay out and dig footings) since those construction processes have the same format and content for the respective design and construction information.

Construction process	Format and Content of Model View	Fragments of sample illustrations
Lay out and dig footings	Plan view color coded according to bottom elevations of the footings (i.e., footings with different bottom elevations are of a different color). It includes only footings, column layout grids, footing piece marks, and dimensions.	
Set deck forms for elevated slab	Reflected ceiling view of elevated slab color coded by bottom-of-slab elevations (i.e., elevated slabs with different bottom elevations are of a different color). It includes elevated slabs, column grids, and dimensions.	

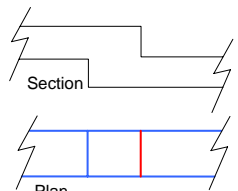
Set anchor bolts of columns	Plan view with the columns color coded according to the type of plate (i.e., columns with different anchor bolt configurations are of a different color). This view must include columns, layout grid, and dimensions.	
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### 3.2.2. Instructions (construction steps) section

This section explicitly states the construction steps that the contractor wants its laborers to follow. The section has several characteristics of the good instructions. It is self-contained, it uses illustrations (when needed) to support step explanations, it organizes steps by tasks, and it contains critical information (trade knowledge is left out) based on the contractor’s judgment.

This section includes an explicit sequence of the construction steps needed to perform the activity described by the field instruction. These construction steps are based on the best construction practices of the company (instead of a particular foreman’s experience) and can be supported by visual aids to illustrate a particular step. The level of detail of these construction steps is, again, up to the company using field instructions, but, as a general rule, construction steps should not include obvious actions (e.g., grab the hammer, hit the nail, etc.) and general trade knowledge but only steps that define a procedure that may have an impact on quality, productivity, safety, and other factors relevant for the contractor (i.e., sustainability, building codes).

Figure 7 shows two examples.

Set column forms	Lay out and dig footings
<ul style="list-style-type: none"> <li>- Move tools and equipment to work area.               <ul style="list-style-type: none"> <li>* Column forms should be in the baskets.</li> <li>* Move baskets with fork lift.</li> <li>* Move ties (usually boxes or buckets).</li> </ul> </li> <li>- Lay down forms at the four column sides.               <ul style="list-style-type: none"> <li>* Place forms on the floor at the four sides of the column.</li> <li>* Use four 12'-6" panels.</li> </ul> </li> <li>- Spray panels with form oil.</li> <li>- Set column forms.</li> <li>- Brace/plumb columns.               <ul style="list-style-type: none"> <li>* Nail braces to 2x4s that hold panels.</li> <li>* Nail the other extreme to a stake in the floor.</li> <li>* Use a plumb @ 1' from the top of the panel.</li> <li>* Make a mark @ 1' from the bottom of the panel.</li> <li>* Check plumb.</li> <li>* Do this in both directions of column.</li> </ul> </li> <li>- Install scaffolding.</li> <li>- Mark pouring height.               <ul style="list-style-type: none"> <li>* Use laser to find the pouring height (height of the column underneath the column cap).</li> <li>* Nail a nail inside the form at the proper height.</li> </ul> </li> </ul>	<p><b>Layout</b></p> <ul style="list-style-type: none"> <li>- Move tools and equipment to work area.</li> <li>- Paint soil according to drawing section.</li> <li>- For step footings, paint the bottom step the same color as the edge of the footings and paint the top step for the form with a different color.</li> </ul> <div style="text-align: center;">  </div> <p><b>Dig</b></p> <ul style="list-style-type: none"> <li>- Move tools and equipment to work area.</li> <li>- Set up laser making sure that laser beacon is level.</li> <li>- Place receiver on 2x2 and adjust receiver to bottom of footing.</li> <li>- Check elevation and give feedback to backhoe operator.</li> <li>- If potential rain, pour muddsill.</li> </ul>

*Figure 7. Examples of the instructions section. The left example shows organization of the steps based on the tasks acting on the building elements. The right example shows a visual aid that supports a particular step. One of the steps references the drawing section of that particular work instruction that is not shown here. The field instruction in Figure 5 also has a visual aid in the instructions section.*

### 3.2.3. Equipment and tools section

This information complements the construction steps of the instructions section by specifying a list of the equipment and tools that laborers need to perform the steps. The purpose of this section is to make the list of these equipment and tools explicit to the laborers. Again, this section does not include general trade knowledge about how to use the equipment and tools.

#### 3.2.4. BOM section

This section uses the concept of material in a broad sense. We consider material any element that will be part of a building component (e.g., concrete, rebar, steel), that supports the installation of a building component (e.g., formwork panels, lumber), or that is a byproduct of an activity (e.g., earth extracted from digging footings). The key feature of the material is that it can be and needs to be quantified, based on the contractor's needs.

Also, note that not all activities involve materials in the sense that we use the term "materials" here. For example, laying out footings (pretty much the layout of any building component) does not need materials.

These four sections (i.e., drawings, instructions, equipment and tools, and BOM) consolidate the information in an all-in-one work instruction with the characteristics of good instructions that we derived from our literature review and our active participation on the jobsite. Field instructions can be used for a range of activities but there are situations for which they may not provide enough benefits to justify their use. We discuss the range of applicability in the next section.

### **3.3. Applicability range of field instructions**

As in any method or tool, field instructions should be used for activities when the benefits of using this formal instruction are greater than the costs of producing the instruction. This assessment depends on the company's practices and the complexity of the activities they perform. However, there are general criteria to determine the applicability.

Regarding the type of activities, the field instructions template is designed to support field activities and not administrative or support activities such as planning, cost control, purchasing, equipment maintenance, etc.

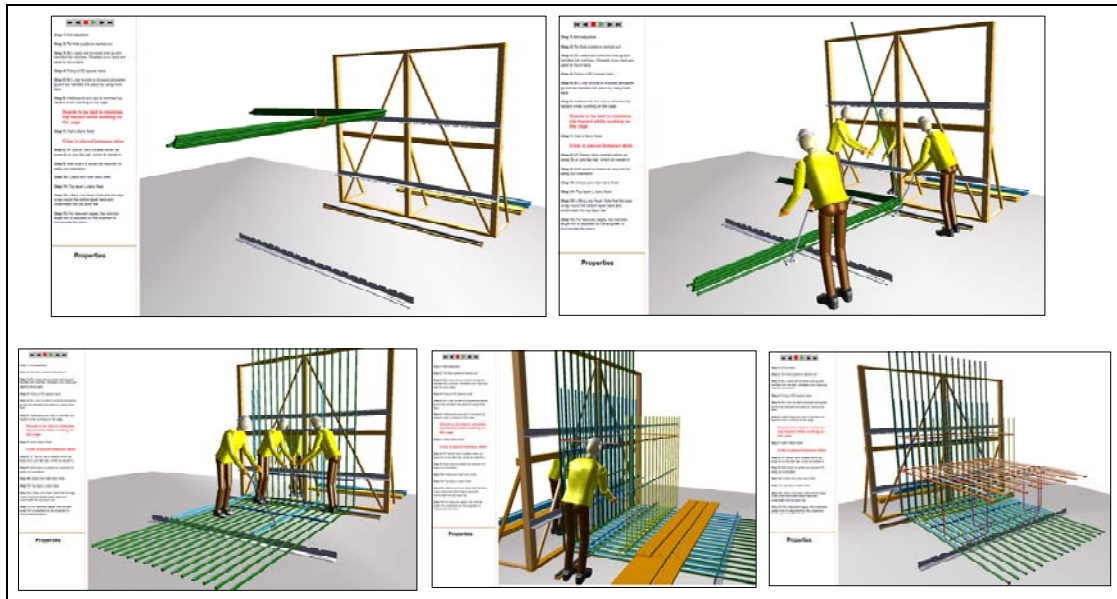
Regarding the activity complexity, it does not make sense to use field instructions for activities that are too simple or where laborers know very well what they have to do. For example, during the field testing in the development phase, we observed that laborers did not need any instruction for pouring concrete as they knew very well what to do and how to do it. Another example is the installation of highly-accurate modular steel structure systems where laborers only need to know the location and orientation of the steel members. Figure 8 shows an address code stamped on the steel members at the factory used by a company to specify the location and orientation of the members (Luttrell, 2008).



*Figure 8. Address code for steel structure members. A manufacturer/installer of steel structures uses this code to tell laborers the location and orientation of the steel members (image courtesy of ConXtech).*

On the other extreme, if an activity is very complicated, it is necessary to reduce its scope to keep the respective field instruction simple. For example, instead of using one field instruction for setting a very complicated embed system in a concrete wall, we can either use a field instruction for each sub-component of the embed system or reduce the work area (or specify a subgroup of walls in the original work area) to include only walls that have the same type of embed system. When highly complex activities are also very important for the project (because they are highly repetitive or affect many other activities), the use of field instructions can be complemented with task-specific training sessions supported by process simulations. Figure 9 shows

snapshots of a process simulation with the respective instructions used for the prefabrication of rebar cages (Arbulu, 2008).



*Figure 9. Snapshots of a simulation of the prefabrication of a rebar cage (Arbulu, 2008). Producing this type of simulations is worthwhile only for important activities (images courtesy of Strategic Project Solutions).*

Regarding the activity scope, field instructions are intended for one day of work, so they are delivered to the laborers for the work they will do that particular day.

However, in some cases (like in the example of the concrete embeds above), it is necessary to reduce the scope of the instruction. Analogously, simple and repetitive activities that still benefit from using field instructions (e.g., installing prefabricated column rebar cages) can use field instructions with scope for several work days.

Now that we have explained the field instructions template, how we developed it and its applicability range, the question is: do field instructions reduce the problems of the traditional verbal instructions?

#### **4. Validation of field instructions**

To answer the question stated above, we must compare the impact that both work instructions (verbal and field instructions) have on the areas where verbal instructions have problems. Therefore, we validated the power of the field instructions template by assessing the reduction of instances of the main problems (i.e., workface questions, rework, low productivity, and unsafe situations) compared to the traditional communication of work instructions (verbal communication and construction drawing sets). We validated the generality, within the CIP concrete domain, by using two different projects with different teams.

The validation shows that the field instructions template reduces the problems produced by the current method of communicating work instructions. It also shows the unforeseen result that using field instructions weakens power hierarchies produced by information access.

The validation methodology we used consisted of 3 steps: produce daily field instructions for one week of work on each construction project, have the laborers use these instructions and, at the end of this period, interview the laborers to qualitatively assess the impact of these instructions.

We initially tried a quantitative evaluation of these instructions' impact. We tried to measure, for cases with and without field instructions, the affected activities' productivity, the number of questions laborers had while doing those activities, the rework hours related to those activities, and the number of unsafe situations and accidents that occurred while working on those activities. However, obtaining timely, accurate, and reliable data from the projects proved to be impossible since the required measurement system was not in place and manual measurement would have been too intensive and disruptive. Consequently, we used a qualitative assessment of the impact on these problems.

The projects used for the validation focused on the construction of cast-in-place concrete foundations and slabs-on-grade for multifamily housing buildings. However, the buildings have important differences that contribute to the generality of the validation. One project is a regular podium building (i.e., elevated post-tensioned slab on top of one floor of concrete columns and walls) while the other is a building where the slab-on-grade is split into two levels and includes a large retention wall.

The structured interview asked the interviewees to assess the impact of the field instructions in their daily work regarding 5 categories compared with the use of traditional verbal instructions. Table 3 explains these impact categories and relates them with the instructions' properties for effective communication.

Table 3. Impact categories. The third column shows the criteria for good instructions that relate to each of the impact categories.

<b>Impact Category</b>	<b>Explanation</b>	<b>Instructions' properties</b> (Emmit and Gorse, 2003)
General impact	General assessment of support to do their work.	All
Workface questions	Questions that laborers have when they are performing their work.	Clear, complete, accurate, and timely
Rework	Work that laborers have to redo because the information they got was wrong or they did not interpret it correctly.	Clear, error-free and accurate
Productivity	Efficient use of time and other resources (people, equipment and tools, and materials).	Clear, concise, meaningful, relevant and timely
Safety	Assessment of safety when they perform their work.	NA



We classified the interviewees in three categories based on their relation with the field instructions: foremen/superintendent (of the cast-in-place concrete contractor), laborers who used the field instructions during the validation week, and laborers who did not use them. This last category includes both laborers working on activities for which we did not prepare field instructions, and laborers working on activities that had field instructions. The latter laborers are the fewest and they were usually low skilled (cannot read either words or drawings) and with very low interest/engagement in the project. These laborers work on very simple tasks and just wanted to be told what to do, limiting their intellectual involvement with those tasks. We decided to include these laborers in the validation to identify if there were significant differences with the other interviewees. They based their assessment on what they saw in the field (the other laborers using the instructions) and our explanation during the interview. Figure 10 shows the answers of the interviewees on a 1-to-5 Likert scale where 1 represents a very negative impact, 3 a neutral, and 5 a very positive one. Positive impacts mean that field instructions are better than traditional instructions to deliver instructions.

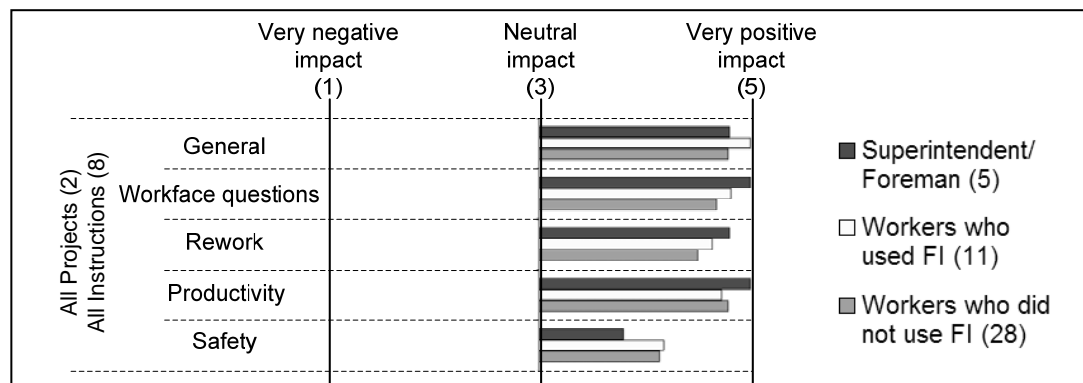


Figure 10. Results of field instructions validation. This graph shows the data from the interviews on the two projects. Based on these positive assessments, we conclude that our field instructions template is better than traditional instructions relative to the problems identified in section 1.

All the interviewees assessed the impact of field instructions positively in all the areas as they felt that using field instructions was much better than relying on verbal

communication. The superintendent/foremen felt that they could better communicate and were particularly happy with the impact on workplace questions. The impact of field instructions on safety was considered to be positive but not as strong as in the other areas. Most of the interviewees mentioned that safety depends finally on the worker. The variation on the assessments made by the different types of interviewees (foremen/superintendents, laborers who used the field instructions and those who did not use them) is relatively small with a slightly bigger difference between the foremen/superintendent and the laborers. Given the small sample, these differences do not have a definitive trend.

A very interesting, and unforeseen, finding from the validation is that workers felt the information was more accessible to everyone and, therefore, it weakened power hierarchies created by information access. This weaker hierarchy contributed to the purpose of field instructions (i.e., improve communication of design and construction information) as it facilitated the communication between laborers and the superintendent and foremen.

## **5. Conclusions**

The current method to deliver work instructions (verbal communication plus construction drawings) negatively impacts the work in the field by raising questions at the workplace, increasing the rework, lowering labor productivity, and creating unsafe situations.

In response to this problem, we presented a format and content template for work instructions (field instructions template) as a better means to communicate design and construction information to CIP concrete construction laborers. Developing this template, we formalized characteristics of good work instructions for construction based on literature review and active participation in projects.

Based on the validation shown in section 4, we claim that our field instructions template is better than traditional practice as it reduces the above problems. The use of this template will allow better field communication and tracking of the work done and the construction methods used. The practical implications of this are: lower costs for the contractor due to less rework, higher productivity, and safer operations; and better contractor's knowledge management since there is an indexed record of the specific design and construction information used for activities in the project that can be tracked by date, building element, resource, and location.

This template contributes to the knowledge in the construction domain as it defines the content and format of good work instructions for construction. Previous research did not present explicit format and content formalizations. Even outside the construction domain, we were able to collect characteristics of good instructions but not explicit definitions of format and content. We also discovered in this process that the step-by-step approach, suggested by previous research in assembly instructions, does not work well in the construction domain. Consecutively, we suggest the use of an all-in-one approach.

In the process of defining our field instructions template, we extended the OAR activity ontology by including a work area defined by the three typical levels of LBS for building projects. This extension defines the AROW ontology.

The major limitations of the presented template are the following:

- We developed the template for a specific domain (CIP concrete operations). Other construction disciplines may have particular characteristics that require a different information format or content in the work instruction.
- The validation process was qualitative only (reliable quantitative data proved impossible to obtain during this research).

- The template is for field construction operations only and does not address support activities such as material movement and equipment maintenance, or managerial activities such as quality control and progress reporting.
- The scope of this research is the delivery of design and construction information to the laborers so the template does not allow capturing feedback information from the laborers at the moment of performing the activity described in the field instruction. However, this feedback information is key to keep an indexed record of the “as is” information that includes product and process changes done in the field (i.e., actual product dimensions and locations, and actual construction steps, equipment and tools, and materials), quality related comments, suggestions, etc.

We plan to continue our research to extend the scope of this template to other construction disciplines (e.g., plumbing, framing, and steel structure), perform quantitative validations of the impact of the template, and integrate feedback information in the template. Also, we suggest future research using a different methodology to derive good instructions for construction. For example, Heiser et al. (2003) and Agrawala et al. (2003) used cognitive psychology to define principles for assembly instructions. We believe that, although hard to apply and maybe too general for obtaining a specific format and content template, it would be interesting to apply this methodology on a future study to contrast the results with the presented field instructions template.

Finally, there is a big opportunity to automate the production of field instructions as the format and content of these are now clearly defined. We plan to continue our research to answer how the input information (design and construction knowledge) of such automation has to be defined.

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