

# Classification of detection states in construction progress monitoring

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**ABSTRACT:** The research conducted in this publication focusses on automated progress monitoring. The recording of the current as-built state of a construction site is achieved by photogrammetric methods (e.g. UAVs) and compared to an as-planned (4D) BIM model. To visualize the detected elements and evaluate their respective detection rate, a schema for the classification of each individual element is presented. It compares the as-built ground truth with the actually detected elements and thus facilitates a quick and easy interpretation of the current construction state. Temporal data from construction schedules is added to further complete the provided information through visualization. Additionally, the classification helps to identify possible lacks of detection algorithms. New parameters for detection algorithms can be applied and the results are immediately visible with an easily understandable color scheme.

## 1 INTRODUCTION

In construction, progress supervision and monitoring is still a mostly analog and manual task. To prove that all work has been rendered as defined per contract, all performed tasks have to be monitored and documented. The demand for a complete and detailed monitoring technique rises for large construction sites where the complete construction area becomes too large to monitor by hand efficiently, and the amount of subcontractors rises. Main contractors that control their subcontractors' work, need to keep an overview of the current construction state. Regulatory problems add up on the requirement to keep track of the current status on the site.

The ongoing digitalization and the establishment of building information modeling (BIM) technologies in the planning of construction projects can facilitate the use of digital methods in the construction phase. In an ideal implementation of the BIM idea, all semantic data on materials, construction methods, and even the process schedule are information consistent and connected. Therefore, it is possible to make statements about cost and the estimated project finalization. Possible deviations from the schedule can be detected and succeeding tasks are easy to identify.

This technological advancement allows new methods in construction monitoring. As described in (Braun et al., 2015) the authors propose a system for automated progress monitoring using photogrammetric point clouds. The main idea is to use common

camera equipment on construction sites to capture the current construction state ("as-built") by taking pictures of all building elements (Tuttas et al., 2016). When sufficient images from different points of view are available, a 3D point cloud can be produced with the help of photogrammetric methods. This point cloud represents one particular timestamp of the construction progress and is then compared to the geometry of the BIM ("as-planned"). Details on the generation of the point clouds and the comparison algorithms can be found in (Tuttas et al., 2014, 2015).

For the visualization of the comparison results, of the detected elements and in order to verify the used algorithms, all gathered data are stored in a database that is accessible to the *progressTrack Viewer*. This tool is developed in the frame of this research project. It displays all building element information and in addition the process data. The detected elements are highlighted for an easy identification. Figure 2 shows one of the construction sites that were used for case studies during this research. The building mainly consists of in-situ concrete elements that were cast with formwork on site. In the screenshot, depicted in this figure, one specific acquisition date is selected and all detected elements are highlighted by means of a dedicated color. Green coloring represents elements that have been built and are detected and confirmed through the point cloud. All yellow elements are built but were not confirmed through the point cloud.

There are several reasons, why some of those elements were not detected:

One of the main reasons is occlusions. During construction, large amounts of temporary structures like scaffoldings, construction tools, and construction machinery obstruct the view on the element surfaces. Limited acquisition positions further reduce the visible surfaces and hence the overall quality of the generated point clouds. As introduced in (Huhnt, 2005), technological dependencies can help to formalize the schedule sequence. A precedence relationship graph (PRG) can hold this information and help to identify the described occluded elements (Braun et al. 2015b).

Another reason for weak detection rates is building elements which are currently under construction. As those elements count towards the overall progress, they must not be missed and play a crucial role in defining the exact position in the current process. Challenging parts are in general all construction methods, whose temporary geometry differs largely from the final element geometry. This accounts e.g. for reinforcements or formwork. On the one hand, formwork may obstruct the view of the element and thus make it impossible to be detected. On the other hand, the plane surface of a formwork for a slab might be detected as the surface of the slab itself and thus lead to false positives (Turkan et al., 2014).

Due to these challenges, detection algorithms need enhancements and require thorough testing. For the respective field studies, the ground truth is required to validate calculated results. Concerning construction monitoring, different construction sites are required and in addition, data recording should be tested under varying conditions to get different use cases for robust results. In the scope of this research, various case studies have been conducted for thorough testing results. Special focus lies on the points, that are counted as relevant for the individual surfaces of construction elements. Thus, thresholds need to be defined to filter unneeded and false points. Since these thresholds depend on various conditions like acquisition accuracy or construction methods, parameter studies are required for valid results.

This necessitates classification schemes to categorize all possible detection states.

## 2 RELATED WORK

Process monitoring has become a heavily researched topic recently. Capturing the as-built construction status is mainly achieved by laser scanners or cameras using photogrammetric methods. For the comparison with the as-planned state (BIM 3D geometry), three methods are currently established

- i. Comparison of the as-built point clouds with points from the transformed as-planned geometry.

These methods compare point clouds that are

acquired by laser scanners (Bosché, 2010; Turkan, 2012) or photogrammetric methods and derived point clouds from as-planned surfaces (Kim et al., 2013). This is mainly done by Iterative Closest Point (ICP) algorithms.

- ii. Feature detection in the acquired images from the as-built state.

Using feature detection algorithms like SIFT, construction elements are directly identified from the acquired images. The derivation of the progress is based on a Bayesian approach, while learning the thresholds based on Support-Vector-Machines (SVM) (Golparvar-Fard et al., 2011).

- iii. Matching the as-built point cloud onto the as-planned geometry surfaces.

This approach matches relevant points from the point cloud directly onto triangulated surfaces of the as-planned model (Tuttas et al., 2015).

Monitoring with laser scanners or cameras proved to be helpful according to these studies. It is possible to identify individual elements for each use case. In fact, most publications focus on identifying one particular element. All of these approaches lack the possibility to clearly identify building elements under construction. A first attempt to solve the problem of elements under construction is published by (Han et al., 2015). However, Han focusses on visibility issues. E.g. when an anchor bolt for a column is invisible as it is embedded into the concrete, it still must be present since the column on top of it requires the anchor bolt for structural reasons.

Process planning is often executed independently from architectural and structural design. Current research follows the concept of automation in the area of construction scheduling. Binding process information and the underlying building information model provides additional information that can be used in the context of progress monitoring.

Tauscher (2011) describes a method that allows automating the generation of the scheduling process at least partly. He chooses an object-oriented approach to categorizing each component according to its properties. Accordingly, each component is assigned to a process. Subsequently, important properties of components are compared with a process database to group them accordingly and assign the corresponding tasks to each object. Suitable properties for the detection of similarities are for example the element thickness or the construction material. With this method, a "semi - intelligent" support for process planning is implemented.

In (Huhnt, 2005) a mathematical formalism is introduced that is based on the quantity theory of the determination of technological dependencies as a basis for automated construction progress scheduling. In (Enge, 2010) a branch-and-bound algorithm is intro-

duced to determine optimal decompositions of planning and construction processes into design information and process information.

Another important aspect for the as-planned vs. as-built comparison is dependencies. Technological dependencies show, which element is depending on another element, meaning, that it cannot be built after the first element is finished. These dependencies can be stored in so-called precedence relationships (Wu et al., 2010). A solution to store these dependencies in graphs is shown in (Szczyty et al., 2012).

However, the visualization and classification of the detection states have not been addressed in detail so far. (Golparvar-fard et al., 2009) have introduced an approach where a color scale for elements ahead of schedule (dark green) over elements on schedule (light green) to elements behind schedule (red color) is shown. This scale requires all elements to be visible and detected. As discussed before, this condition is not met at all times during monitoring.

### 3 CLASSIFICATION METHOD

During the comparison of the as-built and the as-planned state, different detection states occur. As introduced, a classification scheme is required to exactly visualize all possible detection states. In this case, the temporal factor is addressed. The generated point cloud for the as-built vs. as-planned comparison represents the actual situation on site at a certain time. However, this point cloud might not be perfect and have holes or low densities in several spots. For this reason, the detection algorithms might not identify all elements present. In order to correctly handle those elements, each element is considered and categorized independently.

As shown in Table 1, each building element is categorized in three different states:

- i. **As-planned:** whether it should be built at a given time or not, according to the process plan. The main idea behind as-built vs. as-planned comparisons is to detect if there are any deviations on the site compared to this state.
- ii. **As-built:** whether it is actually present or not. This state represents the ground truth and is not available during the as-built vs. as-planned comparison under real conditions. Corresponding data is gathered manually to prove scientific methods and refine them.
- iii. **Detected:** whether it is detected by the detection algorithms or not. This state should equal the “as-built” state (ground truth). However, under real conditions it can only be approximated.

Derived from these three states with each two options (yes/no), the shown 3 x 8 matrix ( $2^3$ ) shows all possible combinations.

Table 1: Detection state cases for the as-built vs. as-planned comparison

#	As-planned (process)	As-built (ground truth)	Detected (comparison)
1	-	-	-
2	X	-	-
3	X	X	-
4	-	X	-
5	-	X	X
6	X	X	X
7	X	-	X
8	-	-	X

These cases can occur due to different reasons. In general, those cases are desirable, where the ground truth and the detected elements align since this proves a correctly working algorithm.

#### 3.1 Description of the classification cases

The mentioned cases have different reasons and importance that shall be discussed hereinafter.

##### 3.1.1 Case 1

The considered element is not planned and also not built and detected. This applies to all elements which are installed at a later time.

##### 3.1.2 Case 2

The element should be present according to the construction schedule, however, it is not yet built and also not detected. This case usually takes effect during a delay of the schedule.

##### 3.1.3 Case 3

This object is built and should also be built according to the process plan. However, it has not been detected during the as-built vs. as-planned comparison.

Possible reasons are the already mentioned occlusions, low measuring accuracy or holes in the point cloud. Too few observation points or a smooth surface are other reasons for a bad point cloud quality. Additionally, low construction quality with too high variations from the as-planned model could indicate a not detected element.

##### 3.1.4 Case 4

In this case, the component is present, however, been neither planned nor recognized. This can occur when the component was built earlier than in the construction process defined and in addition it is obscured or otherwise not recognized.

However, this cannot be detected using the given boundary conditions. The case arises logically from the existing categories. A recognition of this case is

only possible in the context of the research scenarios where the ground truth of the element is known.

### 3.1.5 Case 5

Case 5 is identical to Case 4 with the exception that in this case the element has been confirmed by the comparison. Again, the component has been built too early.

### 3.1.6 Case 6

Similar to Case 1 all categories are identical - the component has been built at the specified time and is also recognized.

### 3.1.7 Case 7

This case is critical. The component is planned and has also been recognized, but it is actually not built. This case is unusual and could be caused for example by an element which is currently under construction which will be completed with a slight delay. The geometry is confirmed by a sufficient amount of points; however, it is not yet completely finished.

On the other hand, this case can also be caused by errors in matching algorithms or weakly defined thresholds.

### 3.1.8 Case 8

This case is a similar situation as case 7, however, could have been caused by temporary structures or construction facilities.

## 3.2 Description and color scheme

The cases listed can all theoretically occur during matching with point clouds. However, based on previously evaluated results, the critical cases where a false positive occurs, meaning geometry is recognized without any actual geometry present, did not occur. Table 2 summarizes the reasons and descriptions for the classification states and corresponding problems. It should be stressed, that the noted problems solely focus on problems regarding the detection itself and not on problems for the construction site (e.g. delayed processes).

Table 2: Description of the classifications

#	Description	Problem
1	Element not yet built	-
2	Process delayed	-
3	Occlusions, low point cloud quality	No detection
4	Early finish, occlusions	No detection
5	Early finish	-
6	Element built	-
7	element under construction, slight delay	False positive
8	Temporary structure detected	False positive

In order to visualize the defined classifications, a color scheme is introduced as depicted in Figure 1. The scheme emphasizes on the critical cases (7 and 8), marking them in red colors.

#	as-planned [process planned]	built [ground truth]	detected [PC to Geometry]	Color
1	-	-	-	Grey
2	x	-	-	Orange
3	x	x	-	Yellow
4	-	x	-	Light Green
5	-	x	x	Green
6	x	x	x	Dark Green
7	x	-	x	Red
8	-	-	x	Dark Red

Figure 1: Color scheme for the classification of detected elements

## 4 IMPLEMENTATION

During the scope of the conducted research project, three test sites have been monitored. The introduced classification scheme is applied to validate its meaningfulness.

### 4.1 Prototype implementation

The results of this research project necessitated a BIM viewer that implements all gathered data and provides detailed element information, tailored to the needs of progress monitoring.

Thus, the *progressTrack Viewer* was developed. The current development stage is depicted in Figure 2. It is based on a WPF framework and written in C#.

Building information models can be imported using the xBIM toolkit (Lockley, 2015). A Gantt diagram is used to display and bind construction elements to their respective processes. The software is connected to a database server that stores all semantic information in one place. The detection results from the implemented algorithms are stored there, too.

During this research, various parameter studies were conducted and the results can be viewed in this viewer. For a detailed evaluation of critical areas, the point cloud can be laid over the as-planned geometry. This feature makes it easier to understand, why certain elements were detected and others were not considered in an algorithm.

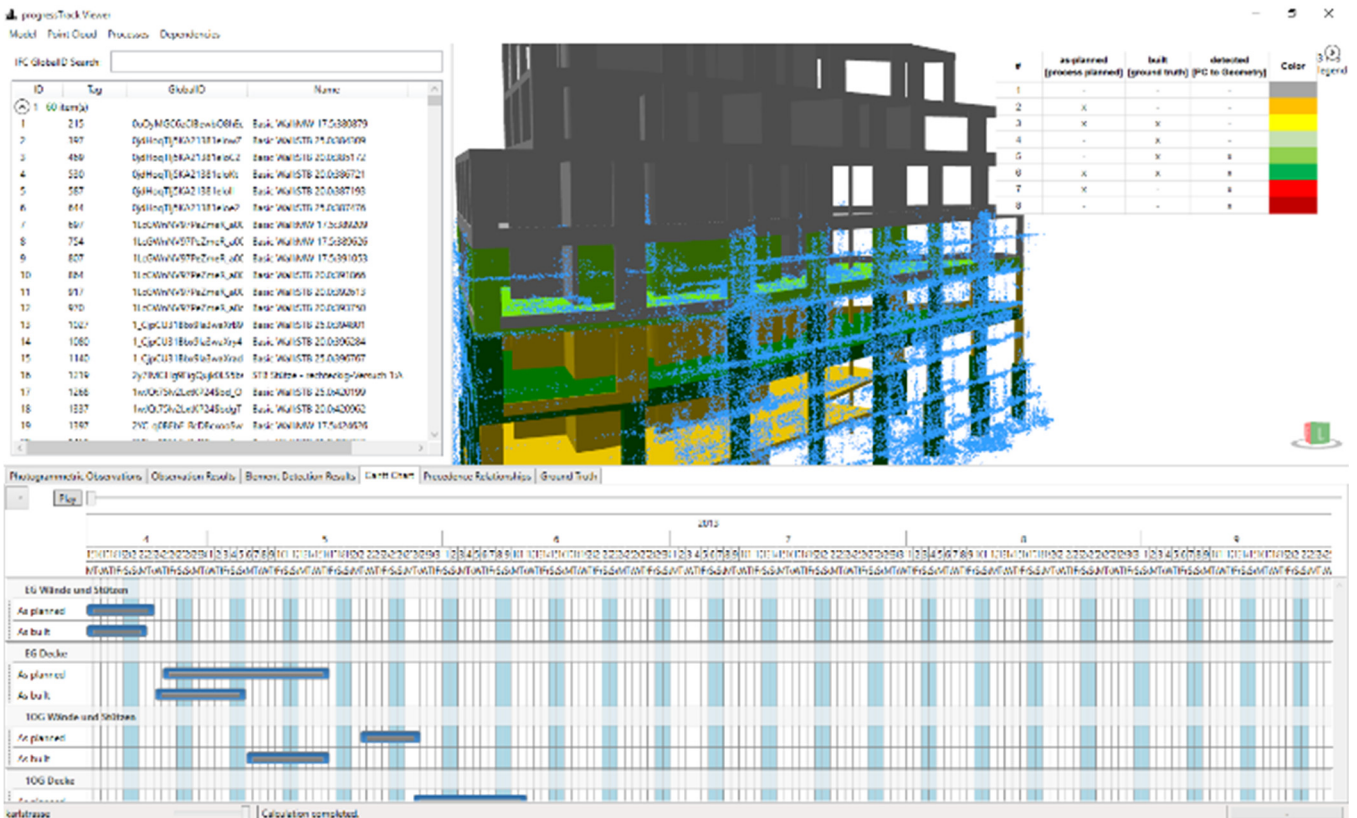


Figure 2: *progressTrack Viewer*: detected elements for construction site "A". Yellow elements are built, but not detected, green elements are built and detected

#### 4.2 Model requirements

For a valuable and precise as-built vs. as-planned comparison, the model itself needs to fulfill requirements regarding the detailing of all construction elements. In the scope of digital element representation, a detailed schema has been developed to classify the detailing of construction elements: the level of detail (LOD).

According to this schema, a BIM necessitates at least LOD 300 for accurate construction site monitoring. The LOD states *"The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element."* (The American Institute of Architects, 2013). Since the exact position, shape and measurements are required, this LOD seems accurate for the desired purpose.

Furthermore, Building Smart defined so called Model View Definitions (MVD) that describe the content of a BIM regarding the included elements and exchange requirements in the AEC industry (BuildingSmart, 2016). The general exchange definitions are labelled "Coordination View" (CV) or as per the newly defined IFC4 "Reference View" (RV).

Those views include all modelled elements with details and constructive parts like reinforcements. This view is required for the as-built vs. as-planned comparison.

Another important aspect regarding model quality are measurement rules for element boundaries. According to german standards, general construction requires an accuracy of around 1cm for 1 meter of element length up to 3cm for 30 meters of element length (DIN, 2013). The point cloud accuracy varies depending on several influences like lighting and is around 1-2 cm. Therefore, this approach is too inaccurate for exact quality measurements, however it is well suited for the as-planned vs. as-built comparison.

#### 4.3 Color Scheme implementation

Depicted in Figure 3, the results for the finished test site "C" are visualized. As discussed, the façade has very good coverage rates while the inner elements were not detected (*case 3*: planned, built, but not detected). The results are immediately understandable

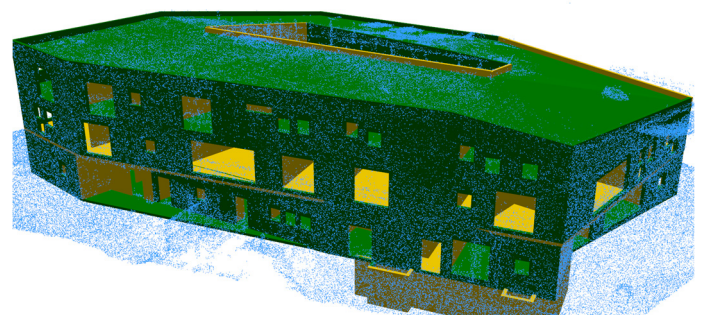


Figure 3: Case Study „Haus für Kinder“ showing the developed color scheme. While the façade has been detected mostly correctly, inner elements could not be detected.



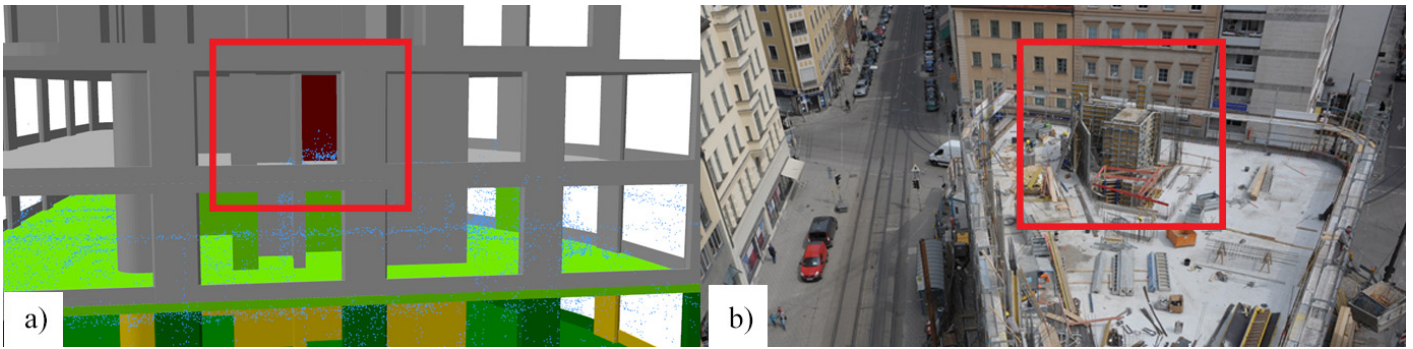


Figure 4: a) Too low thresholds may lead to wrong detection of a column (false positive) b) Picture of the current construction progress, resulting in falsely detected elements

and thus, research results can be visualized in a suitable way.

#### 4.4 Analysis of false positives

Figure 4 a) depicts a small sample of the color scheme. In this case, the as-built vs. as-planned comparison has been calculated with too weak thresholds, resulting in a higher error rate. Marked in light blue, the points that led to this false positive are visible.

They result from rebars, already installed on site, that reached up to the next level and thus led to a matching between the corresponding surface of the column in place. Figure 4 b) shows the problematic case. While the walls and columns one floor beneath the falsely detected element are marked as built / in progress correctly, only a few rebars reach up on the next level.

#### 4.5 Further refinement

As shown in this example, the classification provides useful information for the user of the system, however not all data can be processed correctly. Especially, reasons for undetected elements under construction and large areas, obscured by scaffoldings or other constraints are hard to identify with the help of this classification.

To further detail and refine the classification, additional categories are defined:

- i. **Under construction:** Elements under construction usually require additional elements like formwork or reinforcement, that is installed during the creation of the element. Those construction support elements can be identified with lower thresholds during the as-planned vs. as-built comparison.
- ii. **Derived:** As discussed in (Braun et al., 2014), elements can be ordered according to their dependencies in relation to other elements. This leads to a precedence relationship graph, representing the technological dependencies of all elements of a building. To conclude, an element can be derived as “built”, when following, depending elements

are already marked as built. Thus, enabling algorithms to use this additional information to identify more elements during the as-planned vs. as-built comparison.

- iii. **Previously detected:** Elements that have been detected in a previous time step may be occluded at a later stage due to added floors and slabs over the elements itself. However, previously detected elements do not vanish and already gathered information from previous steps can be used to improve detection rates even further.

This additional information, available through the consequent use of a BIM, bring great benefits to the construction progress monitoring methods and supply data to automate these systems even further.

## 5 DISCUSSION AND FUTURE WORK

This research focusses on the validation possibilities of as-built vs. as-planned element comparison in the scope of progress monitoring. A building information model provides all geometric and semantic data, representing the exact as-planned model of the construction site. The as-built state for individual time steps is generated by photogrammetric means, resulting in a three-dimensional point cloud. As mentioned, this point cloud often lacks quality due to e.g. occlusions or insufficient acquisition possibilities.

For this reason, the comparison of the as-planned geometry and the as-built point cloud returns incorrect or insufficient results that require attention during the development of algorithms and the design of suitable acquisition methods.

The presented classification scheme helps to get a quick and comprehensive overall impression of the current construction state of a building. Additionally, it proves helpful to identify falsely detected elements and visualize them accordingly. This is an essential part of the implementation and testing of new algorithms for the as-built vs. as-planned comparison.

Future improvements will include the use of even more available information through the BIM, like detailed process data and additionally, deeper research

on the impact of detected elements, that are detected with a deviation to the current process plan.

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