Tracking of Secondary and Temporary Objects in Structural Concrete Work

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Abstract

Previous research has shown that "Scan-vs-BIM" object recognition systems, that fuse 3D point clouds from Terrestrial Laser Scanning (TLS) or digital photogrammetry with 4D project BIM, provide valuable information for tracking structural works. However, until now, the potential of these systems has been demonstrated for tracking progress of permanent structures only; no work has been reported yet on tracking *secondary* or *temporary* structures. For structural concrete work, temporary structures include formwork, scaffolding and shoring, while secondary components include rebar. Together, they constitute most of the earned value in concrete work. The impact of tracking such elements would thus be added veracity and detail to earned value calculations, and subsequently better project control and performance. This paper presents three different techniques for recognizing concrete construction secondary and temporary objects in TLS point clouds. Two of the techniques are tested using real-life data collected from a reinforced concrete building construction site. The preliminary experimental results show that it is feasible to recognize secondary and temporary objects in TLS point clouds with good accuracy; but it is envisaged that superior results could be achieved by using additional cues such colour and 3D edge information.

Keywords: Construction progress tracking, Laser scanning, BIM, Object recognition, Temporary objects, Secondary objects

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1 Introduction

Efficient and accurate progress tracking of construction projects is vital for successful project management as it allows corrective decisions to be made in a timely manner. Traditional progress tracking methods require manual data collection and extensive data extraction from different construction documents which distract project managers from the important task of decision making. Recent research efforts to improve progress tracking employ emerging technologies such as three dimensional (3D) imaging, including digital photogrammetry (Golparvar-Fard et al., 2010; Golparvar-Fard et al., 2011; Zhang et al., 2009; Wu et al., 2010) and 3D Terrestrial Laser Scanning (TLS) (Cheok et al., 2000; Shih and Huang, 2006; Bosché and Haas, 2008; Turkan et al., 2011). However, until now these systems have focused on tracking permanent structures only; none have considered trackiing *secondary* or *temporary* structures. Taking the example of concrete forming, temporary structures include formwork, scaffolding and shoring, while secondary components include rebar. The value of tracking temporary and secondary elements is added veracity and detail to the progress tracking process, and consequently to billing efficiency.

This paper describes three techniques for recognizing concrete construction secondary and temporary objects in TLS point clouds, two of which are based on the object recognition system developed by Bosché and Haas (2008) that uses a “Scan-vs-BIM” framework (Guillemet et al., 2012). Two of the techniques are tested using real-life data. Naturally, visual editing could be considered as an alternative to the techniques presented here. However, it would be unmanageable since it requires a significant amount of manual input from the user.

The next section reviews literature on object recognition and provides relevant information related to secondary and temporary construction objects. Sections 3 and 4 detail the proposed techniques for recognizing secondary and temporary objects in TLS point clouds. The experimental results are presented and interpreted in Section 5. A final section concludes the work presented and makes recommendations for future developments and experiments.

2 Literature Review

2.1 Secondary and Temporary Construction Elements in Concrete Works

Formwork is a temporary support structure that is fabricated and installed to support elements of the permanent structure. Formwork by itself is the largest cost component of the construction of a building's concrete structure (CRSI, 2000; Hurst, 1983; Peurifoy and Oberlender, 2011). Vertical shores and scaffolding are used with formworks to support concrete girders, beams, floor slabs, roof slabs, bridge decks, and other members until these members gain sufficient strength to be self-supporting. On the other hand, reinforcing bars, commonly called rebar, are used as a tensioning device in reinforced concrete, holding the concrete in compression. Thus, components like rebar can be considered as secondary construction objects that support the primary object, e.g. a reinforced concrete column (Hurst, 1983; Peurifoy and Oberlender, 2011).

Temporary and secondary structures collectively constitute the major part of the total installed cost of concrete structures (Hurd, 2005; Jarkas and Horner, 2011). Thus, the efficiency of their installation can accelerate the construction schedule, resulting in reduced interest costs during construction and early occupancy for the structure.

2.2 Tracking of Secondary and Temporary Elements

Nevertheless, a thorough examination of the literature reveals a dearth of research into using novel technologies for automated recognition and tracking of secondary and temporary construction objects. Two relevant research works have been identified by the authors. One is by Lee et al. (2010) who developed an algorithm for calculating the quantity of formwork installed from construction site images. Their algorithm requires a user to select a reference form area in the image which has reasonable color and size. The algorithm then searches for the forms in the image by gradually extending the searching area from the selected form area to the neighboring areas. Although high recognition values were reported in this work (as much as 90%), there are issues with sunlight, shadow, obstructions etc., since pictures are used. Furthermore, their work did not address the issue of associating the detection of a particular formwork (temporary object) to particular primary design elements, which is critical to estimate progress accurately.

The second relevant research is the work by Ishida et al. (2012) who developed a system to inspect the quality of a reinforced concrete structure using 3D point clouds obtained with TLS. Essentially, they used a shape recognition technique to detect steel reinforcing bars (rebar) in reinforced concrete structures (this is preceded by the application of a noise filter to the 3D point cloud). Their system successfully identified the reinforcing bars in the 3D point clouds, and was able to count the number of column ties and vertical ties.

Section 4 will present three techniques identified by the authors that could be used to recognize temporary and secondary elements associated with concrete work. Two of these techniques are based on the recognition system initially proposed by Bosché and Haas (2008), thus having the advantage of very marginal execution costs over its current set of applications on a project. The object recognition approach of Bosché and Haas (2008) is reviewed in Section 3.

3 The Automated Object Recognition System

Two of the secondary and temporary element recognition techniques described herein are built upon the object recognition algorithm initially proposed by (Bosché and Haas, 2008; Bosché, 2010) to recognize designed 3D (BIM) model objects in TLS point clouds. This "Scan-vs-BIM" system and its experimental validation are detailed in (Bosché and Haas, 2008; Bosché et al., 2009; Bosché 2010). A short review is given here.

As a pre-processing step, the system requires converting the input 3D model into triangulated mesh format (e.g. STL, OBJ). It then follows a two-step process detailed below:

1. Registration of TLS point clouds with building 3D model
2. Recognition of 3D model objects in TLS point clouds.

3.1 Registration of TLS Point Clouds with Building 3D Model

An initial *coarse registration* is performed, for example by manually matching *n* pairs of points selected in the 3D model and in the scan using commercially available cloud processing software. Another potentially simpler and more accurate coarse registration approach based on plane extraction and matching is also proposed in (Bosché, 2011). A robust *Iterative Closest Point (ICP) - based algorithm* using the point-to-plane framework (Chen-Medioni, 1991; Rusinkiewicz and Levoy, 2001) is then employed to perform the fine registration of the TLS point clouds with the building 3D model.

Point matching: For each scanned data point, a matching model point is calculated as the closest of the orthogonal projections of the data point on the objects' triangulated facets. For ensuring robustness of the matching and consequently registration with respect to outliers, point pairs are rejected when:

(1) The Euclidean distance between two matched points is larger than a threshold τ_D adjusted at each ICP iteration *k* with the formula:

$$\tau_{D,k} = max\left\{2\sqrt{MSE_{k-1}}; \varepsilon_{const}\right\} \quad [1]$$

where MSE_{k-1} is the Mean Square Error (MSE) obtained at the (k-1)th iteration, and ε_{const} is a constant distance that can be interpreted as the maximum distance for which objects with dimensional deviation should be searched. We typically use $\varepsilon_{const} = 20mm$. This value is chosen to be: (a) large enough not to fail to recognize objects due to sensor inaccuracies; (b) large enough not to fail to recognize objects that are built at a position up to 20 mm away from their expected position; but (c) small enough not to mismatch TLS and model points corresponding to different objects.

(2) The angle between the normal vectors to two matched points is larger than a threshold τ_A. We typically use $\tau_A = 45°$. Note that this criterion is discarded when normal information is not available in the point cloud data.

The ICP iterative process is stopped when $\Delta MSE < 0.05mm^2$, where ΔMSE is the MSE improvement between the current iteration and the previous one.

3.2 Recognition of 3D Model Objects in TLS point clouds

At the end of the registration process, the project 3D model and TLS point clouds are optimally registered. Because it is known to which object points were matched at the last iteration, each model object can be assigned a corresponding *as-built* point cloud (sub-set from the complete as-built TLS point cloud).

The analysis of the as-built point cloud can then lead to the recognition of the object itself using a surface-based recognition metric (Bosché, 2010). This metric further requires the calculation of a *virtual as-planned* TLS point cloud using the 3D model and the scanner's location of the registered point cloud.

This point cloud can be segmented in a similar way as with the as-built point cloud, so that each model object can be assigned a corresponding *as-planned* point cloud (sub-set from the complete as-planned TLS point cloud).

Finally, the as-built TLS point cloud can be further analyzed to identify points acquired from occluders (i.e. points with range distance shorter than their expected one). The result is that each model object can be assigned a corresponding *occluded* point cloud (sub-set from the complete as-built TLS point cloud).

After converting the as-planned, occluded and as-built point clouds for each object into *planned*, *occluded* and *recognized* (as-built) *surfaces*, the percentage of recognition $\%_{recognized}$ is calculated as:

$$\%_{recognized} = \frac{S_{recognized}}{S_{recognizable}} = \frac{S_{recognized}}{S_{planned} - S_{occluded}} \quad [2]$$

where $S_{planned}$, $S_{occluded}$ and $S_{recognized}$ are the planned, occluded and recognized surfaces.

$\%_{recognized}$ and $S_{recognized}$ can be used to infer the recognition of each object. An example of rule to infer recognition can be:

if $\left(S_{recognized} \geq S_{min}\right)$ or $\left(\%_{recognized} \geq \%_{min}\right)$, ***then*** the object is considered recognized.

The automated object recognition system presented here was further explored, and combined with schedule information (i.e. with a 4D model) in order to automate progress tracking (Turkan et al. 2011). However, as mentioned earlier, that work focused solely on the tracking of permanent structural elements.

4 Techniques for Recognition and Tracking of Secondary and Temporary Objects in Concrete Work

We describe three (partially complementary) techniques for recognizing concrete construction secondary and temporary object from 3D TLS point clouds. They are described in the sub-sections below and summarized in Table 1. Note that the first two are built upon the “Scan-vs-BIM” automated object recognition system described in Section 3.

Table 1: Proposed techniques for recognizing secondary and temporary elements in TLS Point Clouds, and their applicability for the recognition of such objects in the context of concrete work.

Technique		Applicability to recognize...		
ID	**Description**	Formwork	Rebar	Shoring
1	Extended 3D/4D model with temporary and secondary objects + use approach of Bosché and Haas (2008).	✓	✓	✓
2	Change the default point matching metrics of the approach of Bosché and Haas (2008).	✓	✓	
3	Simple point cloud distribution metrics applied to design object and open space volumes.		✓	✓

4.1 Technique 1

The first technique simply uses the approach of Bosché and Haas (2008) with a 4D model that includes 3D objects for the temporary and secondary objects. This requires creating new design objects for formwork, rebar or shoring. The system's default object recognition settings are then used to recognize those objects.

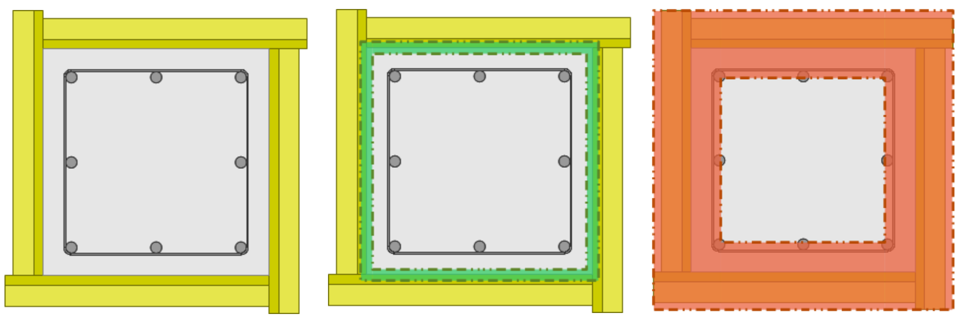
This technique can be applied to track any type of temporary or secondary object, as long as they are in the 3D/4D model. Based on previous related applications, high recognition rates ((>90%) can be expected. Disadvantages are the cost of entering such information into the 4D model for this purpose alone, and the possibility that secondary and temporary (in particular) elements won't be positioning precisely as designed (in particular shoring). Advanced forming systems are an exception.

4.2 Technique 2

The second technique simply changes the default point matching metrics in the approach of Bosché and Haas (2008). This does not require extending the 3D/4D model. Instead, it is hypothesized that formworks and rebar could be detected by searching for matching points that are slightly further away than the default τ_D value. Furthermore, the τ_A threshold is discarded to enable the recognition of formworks used for forming the faces of walls or columns hidden from the scanner's location.

With this approach, illustrated in Figure 1, column formwork (and rebar) and columns themselves should be recognizable by analyzing the recognition metrics, in particular $\%_{recognized}$, obtained for different values of τ_D, e.g. ranging from 10mm to 60mm. A completed column should present high recognition levels for most values of τ_D (in particular 10-20mm), while formworks and rebar should lead to low recognition levels for low τ_D values, and higher recognition levels only for large τ_D values. Indeed, formworks typically have thicknesses of 30mm and more (thickness of the sheeting), while the concrete cover in an RCC column and beams is typically 40mm (1.5in) (American Concrete Institute Standards). Rebar and formwork can be easily differentiated from one another by analyzing whether the matched points are outside (formwork) or inside (rebar) the corresponding column geometry.

Technique 2 can be applied to detect formworks and rebar, but cannot be used for shoring.



(a) (b) (c)

Figure 1: Formwork and rebar recognition using Technique 2:
(a) top view of a concrete column showing the location of the reinforcement and formwork;
(b) With a small value of τ_D, e.g. 20mm, (green volume) only the finished concrete column can be recognized by its surfaces; (c) With a large value of τ_D, e.g. 50mm, (red volume), the rebar and formwork (sheeting) can be detected.

4.3 Technique 3

An "open space" volume is an empty 3D space volume in the 3D model. For example, the open space volume for floor slab shoring can be defined as the cubic space surrounded by four columns (Figure 2).

Given an open space volume, the total number *n* of TLS data points contained within that volume can be calculated, and the number of points per cubic meter η inferred. Then, if $\eta > \eta_{min}$, shoring can be considered detected. (Note that the surface covered by the points, and consequently the surface per cubic meter, could also be used as a more robust approach independent from the distance of the scanner to the negative space volume).

This technique can be applied to detect shoring. Its advantage for shoring is simplicity and effectiveness (as shown later). However, its disadvantage is the necessity to run a routine on the 3D model which can interpret it automatically to create the volumes to be analyzed. This should be generally straight forward, but complex design geometries could present challenges.

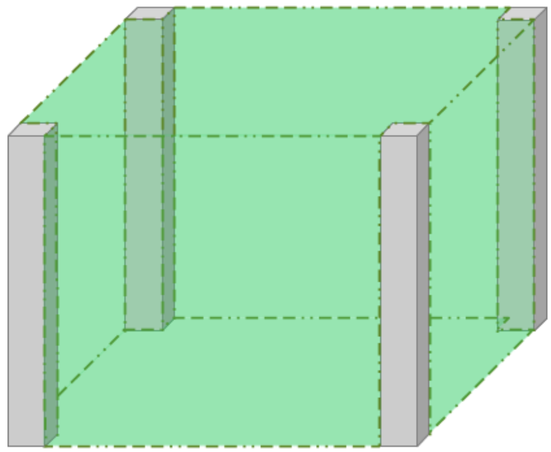


Figure 2: Illustration of the open space volume for concrete shoring defined by four columns.

4.4 Summary

Considering the different techniques above, the first one is the only one that actively recognizes individual secondary and temporary structures considered (formwork, rebar, and shoring). However, this approach requires all those structures to be designed in the 3D model. Furthermore, it also makes the assumption that they will naturally be built where they have been designed, which may not always be true given prevailing standard spatial tolerance limits for these objects (Nunnally, 2004), the latitude given to constructors for shoring layout, and the lack of 3D design models for most formwork systems.

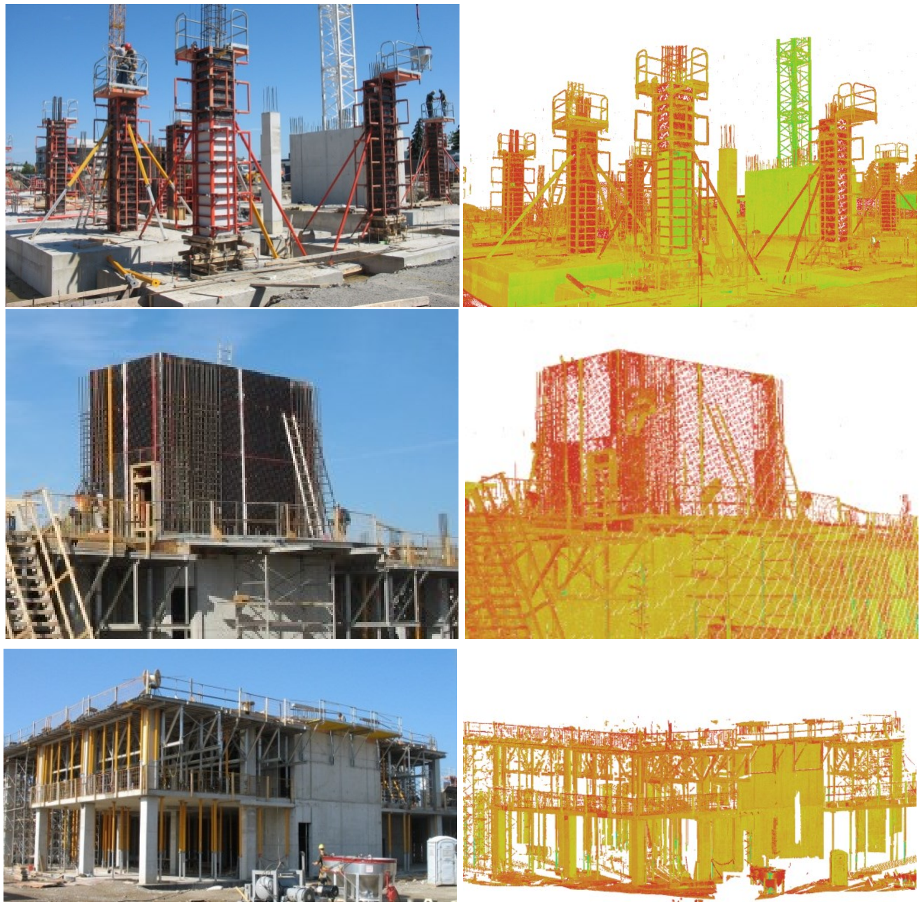
The remaining methods are much simpler to implement, as they do not need any further information but the original TLS point clouds and the original 3D/4D model. Furthermore, they may be more robust with respect to prevailing tolerance specifications for the small deviations between the planned and actual locations of the types of objects being investigated. In this article, Techniques 2 and 3 are investigated. From the analysis, the following recognition process is considered that successively recognizes the completed 3D model objects, formwork and rebar, and finally shoring:

1. **Apply Technique 1** (i.e. using Bosché and Haas's algorithm with a small value of τ_D, i.e. 20mm) to recognize completed 3D model objects. Upon completion, remove the recognized objects from the 3D model and the corresponding matched points from the point cloud.

2. **Apply Technique 2** (i.e. using Bosché and Haas's algorithm with larger values of τ_D) to the remaining of the segmented point cloud from Step 1 to recognize the rebar or formworks for the objects not recognized in Step 1. Upon completion, remove the objects from the 3D model and the corresponding matched points from the point cloud.
3. **Apply Technique 3** (Negative space volume) to the remaining of the segmented point cloud from Step 2 in order to recognize the presence of shoring.

5 Experiments

In order to evaluate the performance of the proposed secondary and temporary construction object recognition techniques, experiments were conducted using a 3D model obtained for the Engineering V Building site at the University of Waterloo, Canada (Figure 3) and eleven different TLS point clouds acquired on eleven different days over a seven month period. The 3D laser scans were acquired using a Trimble® GX 3D laser scanner (Trimble, 2007) that uses time-of-flight technology.



(a) (b) (c)

Figure 3: Temporary and Secondary objects at E5 Building site: (a) column formworks – July 25, 2008; (b) Rebar – September 19, 2008; (c) Slab formworks and shoring – October 9, 2008.

5.1 Recognition of Completed Objects (Step 1)

As a first step to recognize secondary and temporary structures, the algorithm of Bosché and Haas (2008) is first run using its default settings. We use τ_D=20mm, $\%_{recognized}$=50% and $S_{recognized}$=1,000cm^2. This step leads to the recognition of all completed elements, and subsequently the removal from the TLS point clouds of all the points matched to the recognized elements. This is illustrated in Figure 4 for one TLS point cloud. Note that prior publications (Bosché, 2010; Turkan et al. 2010; Turkan et al. 2011) have already demonstrated that this system achieves high recognition performances (>90%) for recognizing large objects like columns, walls and slabs.

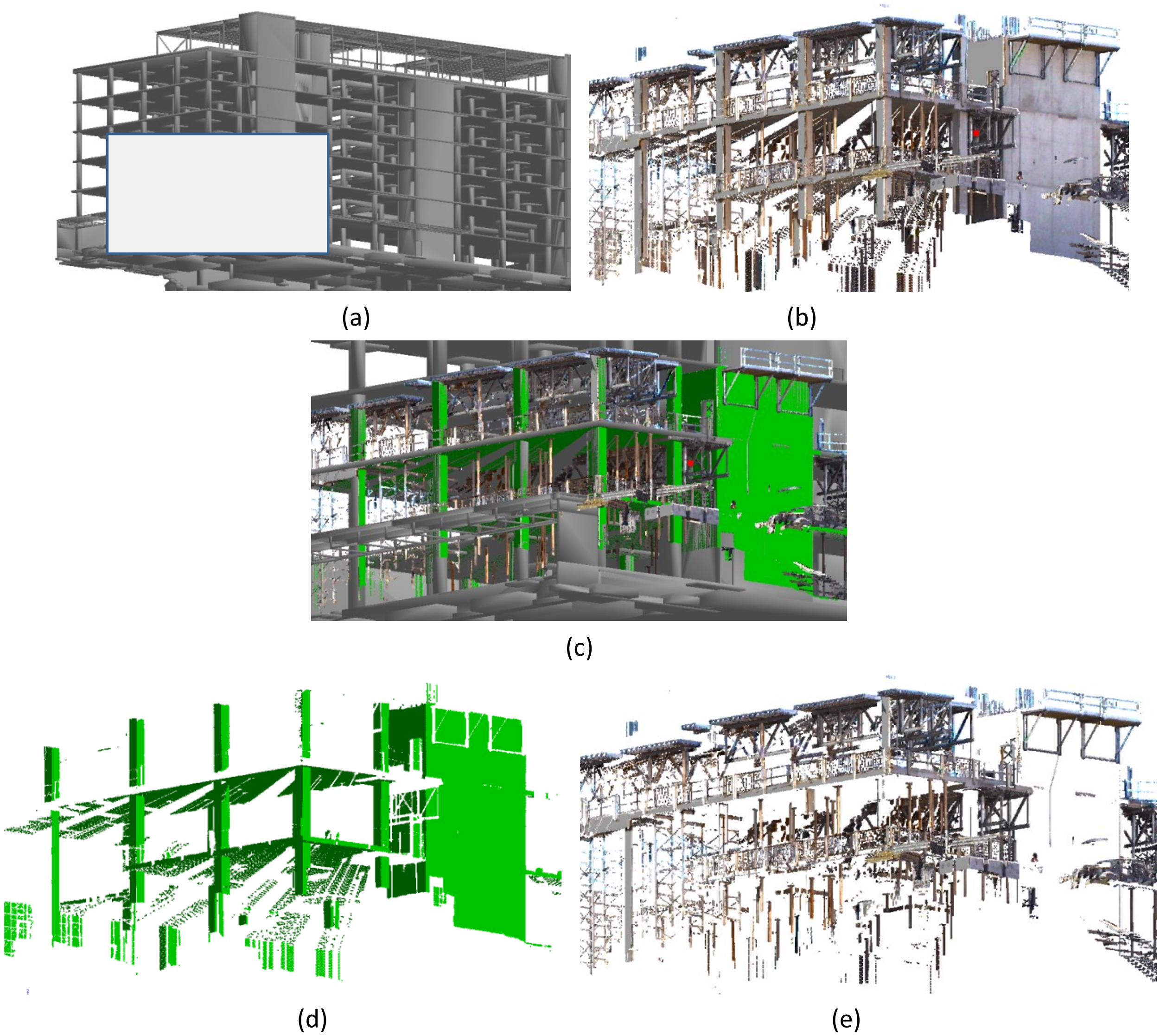


Figure 4: Illustration of the recognition of completed elements, and subsequent filtering of the input point cloud – October 30, 2008. (a) 3D project model with a highlight of the scanned area; (b) 3D point Cloud; (c) 3D point cloud aligned with the 3D model and with points matched to model elements colored in green (d) Sub-cloud of all matched points (d) Sub-cloud of all non-matched points that is further processed to detect rebar, formwork, and shoring.

5.2 Recognition of Formwork and Rebar (Step 2)

Technique 2 (Bosché and Haas' algorithm with larger values of τ_D) was tested with values of τ_D ranging from 10mm and 60mm in order to identify whether rebar and formwork could be distinctly differentiated from completed objects. Five of the Engineering V Building TLS point clouds were used here which collectively contain data from 111 column, floor and wall objects in different construction states, namely: “built” (i.e. completed), “formwork” and “rebar”. The detailed numbers of objects per category are given in Table 2. Examples of the scans used are shown in Figure 3.

Table 2: Number of columns, walls and floors in the different construction stages contained in the scans used to test Technique 2.

Object Type	Built	Formwork	Rebar
Column	52	3	7
Wall	14	6	1
Floor	3	2	N/A

The experiment results are summarized in Figures 5 to 7 for columns, walls and floor slabs respectively. Overall, it appears, as expected, that recognition levels for objects in “formwork” state show very low $\%_{recognized}$ for values of τ_D <30mm, but then clearly increase from 30mm onwards. This pattern is clearly different from what is observed for “built” objects for which large values of $\%_{recognized}$ (>50%) are obtained over the entire range of τ_D (in particular from 20mm). Objects in “rebar” state show similar patterns as those in “formwork” state, which was also expected. Therefore, it can be concluded that the analysis of the variation of $\%_{recognized}$ over the suggested range of values for τ_D can be used to recognize and distinguish the construction states of concrete structures, or, in other words, to recognize and distinguish completed objects, formworks and rebar.

Despite these very encouraging results, some of the patterns shown in Figures 5 to 7 need further analysis and explanation:

- **For objects in “built” state, while $\%_{recognized}$ values are generally high across the range, lower values are observed for τ_D≤20mm.** The two main reasons for this are: (1) measurement errors by the scanner; and (2) minor errors in the registration process for aligning the laser scans and BIM model.
- **For floor slabs in “built” state (Figure 7), the increase in $\%_{recognized}$ with τ_D is not as significant as for columns and walls.** The main reason for this discrepancy it that in the CAD model used in the experiments, the floor slab objects covered entire floors, while in practice these are poured in sections. Therefore, in the reported experiments the system tends to seriously overestimate $S_{planned}$. This can be addressed simply by ensuring that the BIM model used with the software

actually contains floors (and also walls and columns) that are split into sub-elements reflecting the actual construction process.

- **For walls and floor slabs in "formwork" state, the increase in $\%_{recognized}$ with τ_D is not as significant as for columns, and also presents increasing variance.** The authors have identified two reasons for this: (1) The level of detail of the BIM model, as discussed at the end of the previous bullet; (2) Formworks for walls and floors are typically larger than those for columns – in particular the formwork joists (floor) or struts (walls) – so that points scanned on those elements would only be recognized for τ_D>60mm.
- **For objects in "rebar" state, the increase in $\%_{recognized}$ with τ_D is not as significant as for objects in "formwork" (and "built") state:** The reason for this is that the surface covered by rebar is simply lesser than the one covered by the finished element (due to the holes in the rebar), so that $S_{recognized}$ will always be smaller for objects in "rebar" state. Furthermore, rebar is typically loosely installed prior to be positioned within formworks. The bending of loose rebar can result in some of it being at distances from the final object surface larger than 50mm, which further reduces the values of $S_{recognized}$ that can be obtained.

Overall, these results show that the variation of $\%_{recognized}$ over the proposed range of τ_D values is a fairly good predictor of the construction state of concrete structure elements ("built", "formwork" and "rebar"). Figure 8 and Figure 9 show an example of the results obtained for a scan after Technique 1 and Technique 2 are successively applied.

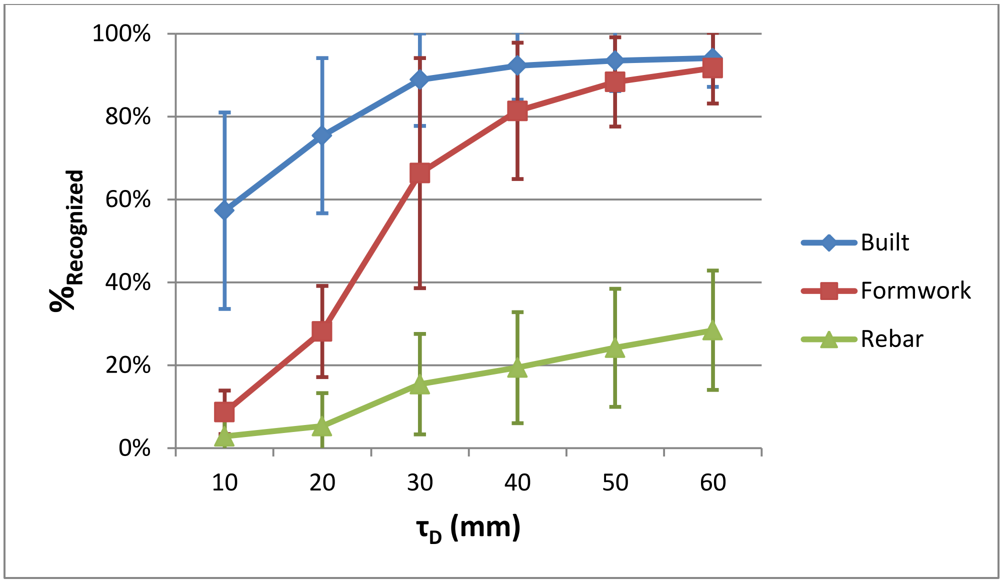


Figure 5: Column recognition performance ($\%_{recognized}$) for different values of τ_D and at different construction stages. The curves show the average and standard variation of $\%_{recognized}$.

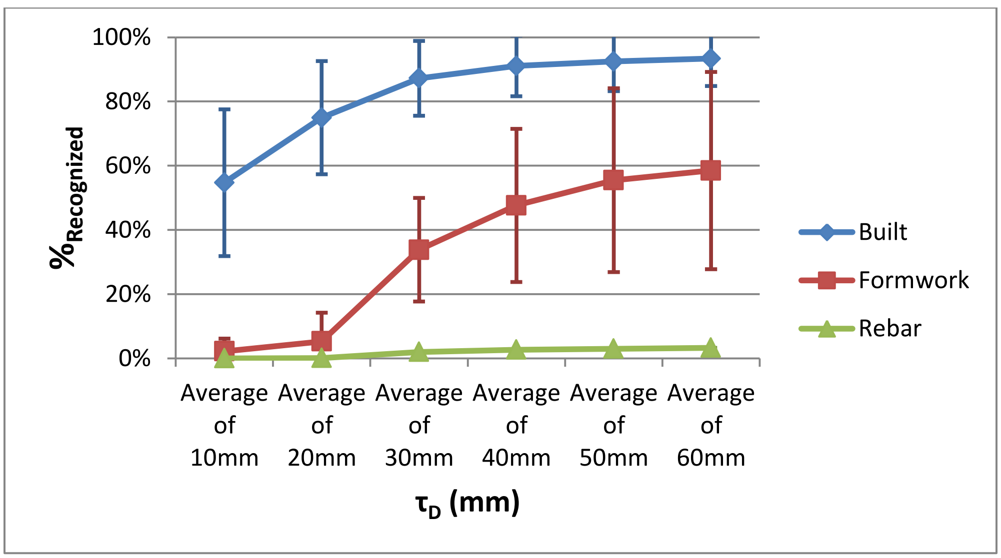


Figure 6: Wall recognition performance ($\%_{recognized}$) for different values of τ_D and at different construction stages. The curves show the average and standard variation of $\%_{recognized}$.

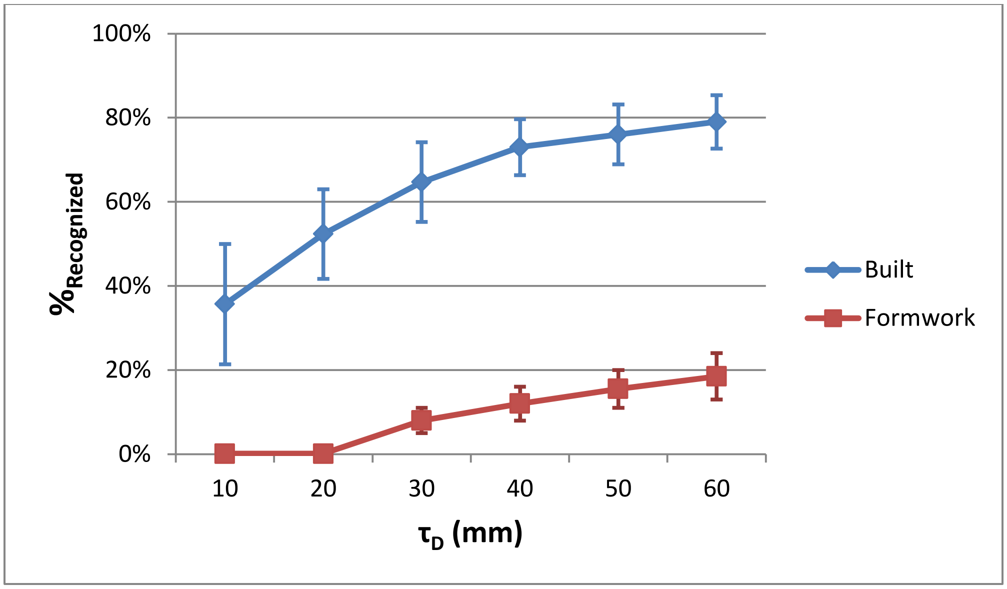


Figure 7: Floor recognition performance ($\%_{recognized}$) for different values of τ_D and at different construction stages. The curves show the average and standard variation of $\%_{recognized}$.

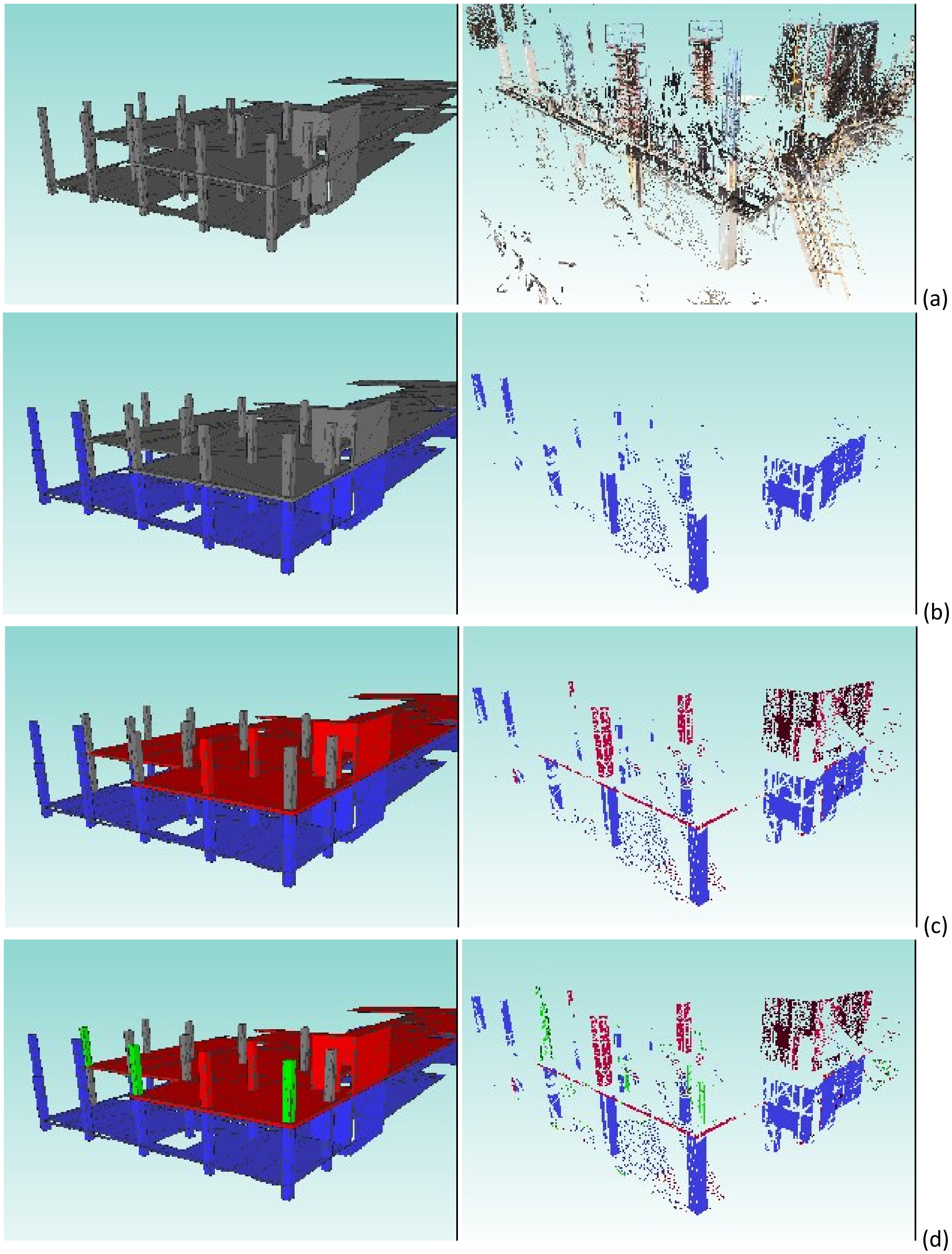


Figure 8: Illustration of the recognition of concrete structure elements in state "built", "formwork" and "rebar": (a) the initial model and point cloud;
(b) model shows objects recognized in state "built" in blue, and corresponding scan points;
(c) model further shows objects recognized in state "formwork" in red, and corresponding scan points;
(d) model further shows objects recognized in state "rebar" in green, and corresponding scan points.

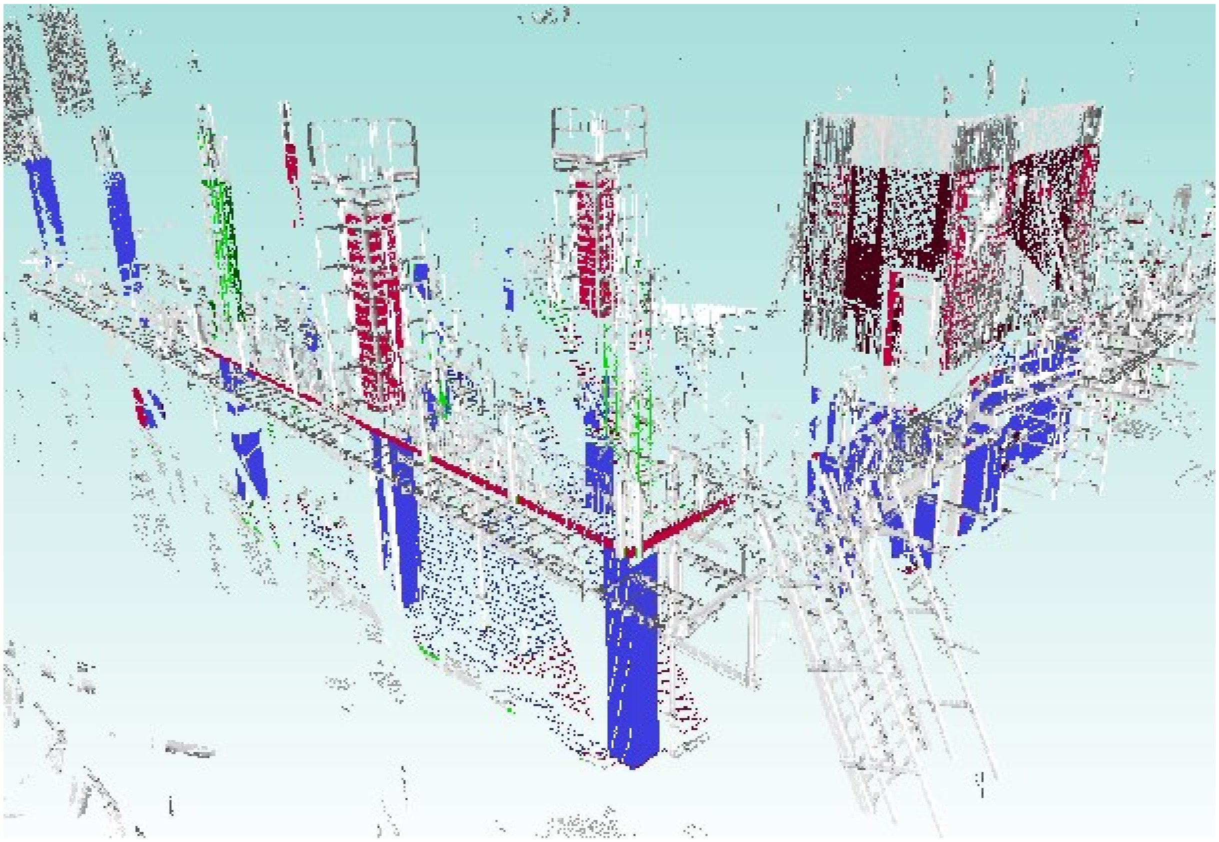


Figure 9: Illustration of the recognition of concrete structure elements in state "built", "formwork" and "rebar": combined results from Figure 8 as well as the remaining point from the initial cloud.

5.3 Recognition of Shoring

In Table 1, two different techniques are proposed for recognizing shoring in 3D laser scan point clouds: (1) Extended 3D/4D model with temporary and secondary objects and use approach of Bosché and Haas (2008); and (2) Simple recognition metrics applied to open space volumes. Here, only the second technique, applying simple feature metrics to the open spaces defined by design objects, is tested for the reasons explained earlier. While open spaces between sets of columns could be identified automatically, the results reported here were obtained using the Trimble® Realworks® manual segmentation tool. The segmentation tool allows the user to select a set of points from the point cloud by defining boundaries using its polygonal framing function; the tool reports the number of points in the defined volume (Figure 10). Separately, the corresponding volume (in m^3) of the defined volume is calculated using the structural BIM model and commercial BIM software (Autodesk® Revit® was used here).

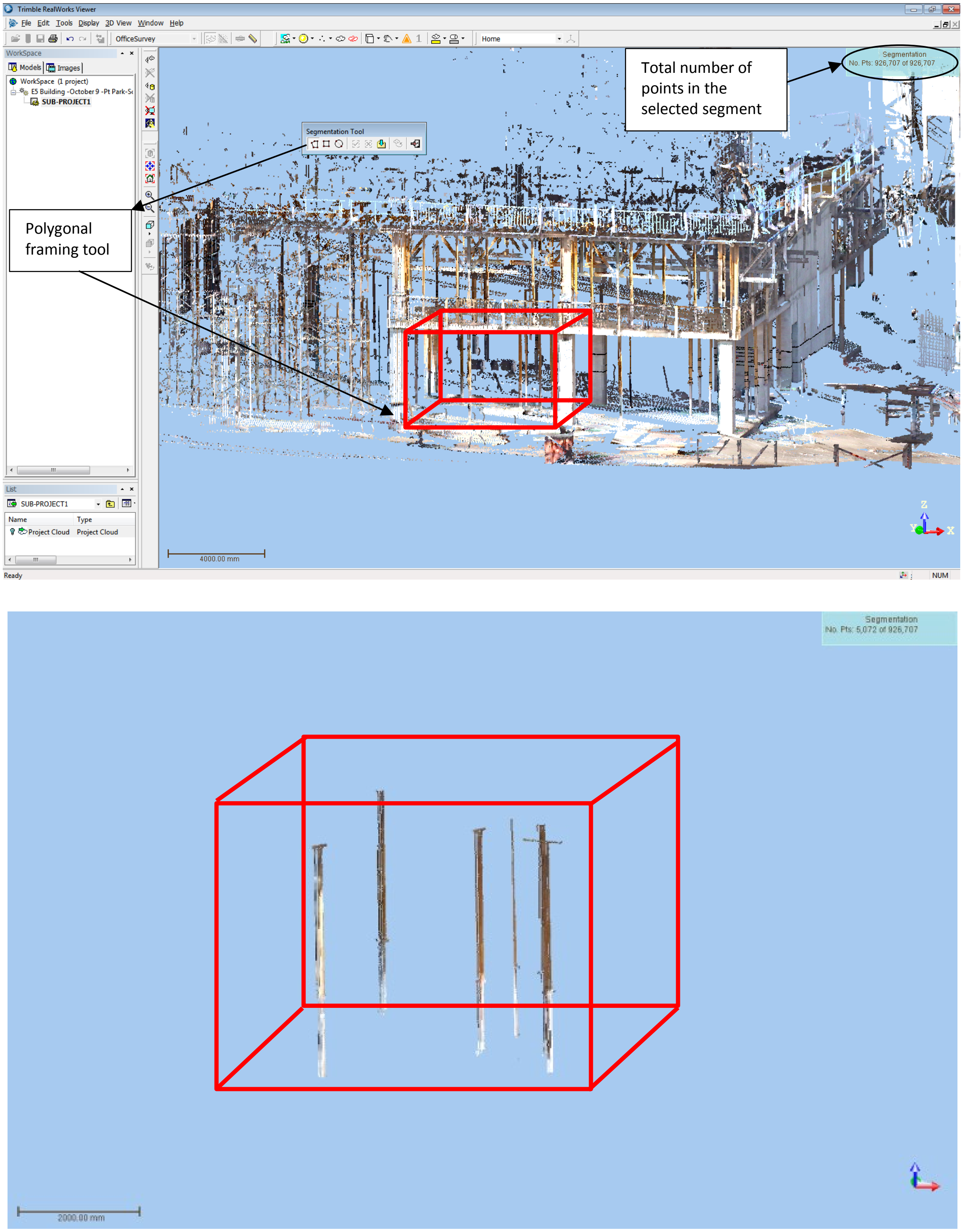


Figure 10: Illustration of the use of the manual segmentation tool of Trimble Realworks© (a) to implement Technique 3 (b).

50 open spaces that have shoring and another 50 open spaces that do not have shoring were selected from the 3D laser scan point clouds of the Engineering V Building, and tested (Table 3) using the technique detailed above. Table 3 presents the number of points per cubic meter for the both groups. Figure 11 summarizes the information presented on Table 3. It can be seen that the number of points per cubic meter varies between 20 and 40 (column 4 in Table 3) if there is no shoring, and between 60 and 100 (column 3 in Table 3) if there is shoring in the selected open space volume (these results were obtained with a relatively constant scanner-volume distance so that the scanning resolution does not impact the results). Using a threshold of 50 points per cubic meters would lead to a 100% recall and 100% precision.

However, it can be argued that wrong classification of open volumes could still happen, with false positive (when shoring does not exist but the point density in the open volume is large) as well as false negative (when shoring exists but the point density is small) results. Construction sites are very dynamic environments where a number of operations are performed simultaneously (Hegazy, 2002). Therefore, the selected open space volumes may be occupied by people, equipment, materials etc., and this may result in false positive results. On the other hand, occlusions from other objects located between the laser scanner and the open space may prevent the recognition of existing shoring, and thus lead to false negative results. The first case can be addressed by further analysing the organization of the identified points within the volume. The second can be addressed by developing a means to estimate the "visible open volume" and thus infer a level of confidence in the result. This would use a similar procedure as the one currently used for calculated occluded surfaces in the object recognition system of Bosché and Haas (2008). These approaches will be investigated in future research, if additional experiments from other building projects indicate reduced recognition performance, with significant amounts of false positives and false negatives.

Table 3: Number of points in the inter-column volumes

Scan Date	Negative space ID #	Number of points / m^3	
		Shoring	No shoring
2008-09-08	1	83	24
-	2	84	25
2008-09-11	3	88	26
-	4	83	29
2008-09-16	5	79	32
-	6	83	31
-	7	90	27
-	8	79	30
2008-09-19	9	66	28
-	10	65	30

-	11	64	32
-	12	73	29
2008-09-26	13	85	27
-	14	74	32
-	15	88	30
-	16	74	29
-	17	85	27
2008-10-09	18	98	30
-	19	73	24
-	20	78	25
-	21	64	30
-	22	85	26
2008-10-17	23	83	31
	24	66	28
	25	72	37
-	26	77	30
-	27	85	29
2008-10-24	28	79	31
-	29	73	36
-	30	70	30
-	31	90	31
-	32	79	32
2008-10-30	33	75	30
-	34	78	29
-	35	81	31
-	36	75	30
-	37	91	35
-	38	92	32
-	39	75	35
-	40	82	30
2008-11-06	41	82	30
-	42	83	37
-	43	84	35
-	44	88	32
-	45	73	38
2009-04-17	46	76	36
-	47	72	38
-	48	78	37
-	49	84	38
-	50	71	28

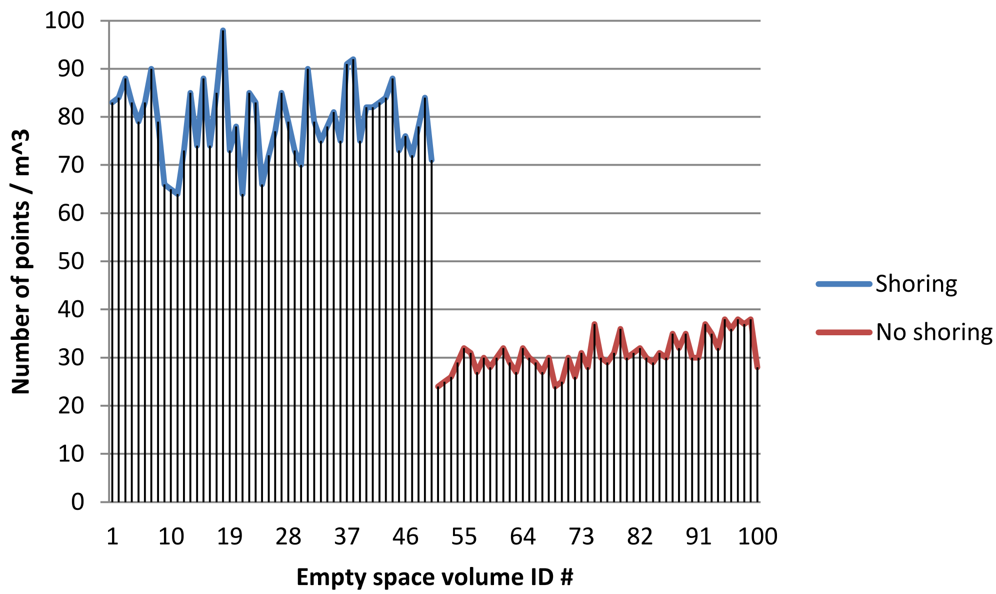


Figure 11 Distribution of number of points per cubic meter in the volumes that have shoring and no shoring.

6 Conclusions and Recommendations for Future Work

In this paper, three techniques for recognition of concrete construction secondary and temporary objects from 3D laser scan point clouds are proposed. Two of these techniques proved to be quite effective to recognize formwork, rebar and shoring using real life data obtained from the Engineering V Building construction site.

Technique 2 leverages the automated object recognition system of Bosché et al. (2008). It requires analyzing the level of recognition $\%_{recognized}$ within a range of values of τ_D from 10mm to 60mm. This technique was used for formwork and rebar recognition. Experimental results have shown that it is feasible using this approach to distinguish whether objects are in state “built”, “formwork” and “rebar”. Different settings may be necessary depending on the type of object (columns, walls or floors), as the type of object impacts formwork thickness or rebar cover. Such information will eventually be contained within the BIM model, so that the thresholds could be set automatically for each object. However, it has also been shown that the Technique’s performance is sensitive to accuracy of the scan-model registration and the accuracy of the BIM model reflecting the construction process.

Technique 3 is an application of a simple metric to open spaces defined by design objects (cubic spaces surrounded by four columns were used here) for shoring recognition from TLS point clouds. The experimental results have shown that it is feasible to differentiate spaces that have shoring and no shoring using this simple metric. Although the open spaces were selected manually, these could be automatically defined using the BIM model. It is however acknowledged that the current simple metric, while resulting in perfect recognition rates for the experiments reported here, may not be very robust and should be extended with additional processing. For example, to ensure the recognition of shoring, algorithms can be developed that would more actively recognize individual shores within the point clouds contained in each open space using techniques such as the Hough transform for 3D edge detection. Corresponding research is ongoing.

Overall, while the seemingly simple approaches (considering the complex foundational software developed to support them) tested in this paper have shown to be quite powerful, future research should explore techniques that could strengthen the recognition of secondary and temporary concrete construction objects. The integration of color information within the recognition framework has great potential as rebar formwork and shoring typically have colours that are quite different from finished concrete (see Figure 3 for example). Furthermore, more detailed object recognition algorithms should be investigated, such as the approach by Ishida (2012). Technique 1 described in this paper, using expanded 3D model that includes concrete construction temporary and secondary objects, also needs to tested and compared.

Finally, studies should be conducted to actually integrate these results of the recognition of the construction state of concrete structures within progress tracking systems (such as the one described in (Turkan, 2012)) and measure the resulting improvement in progress tracking.

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